ADVERTISEMENTS

Dark Energy and the Accelerating Universe

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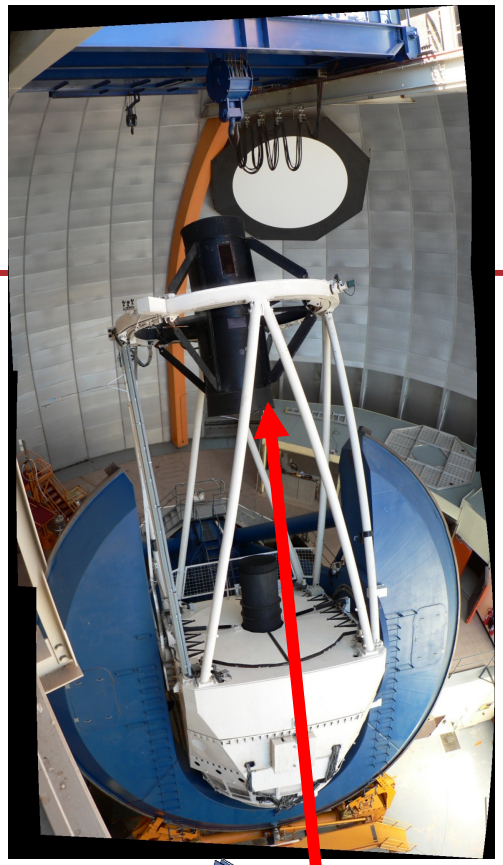
Feb 13 Colloquium by Dragan Huterer on Dark Energy

Co-author of Annu. Rev. Astronomy and Astrophysics 46, 2008

Outline

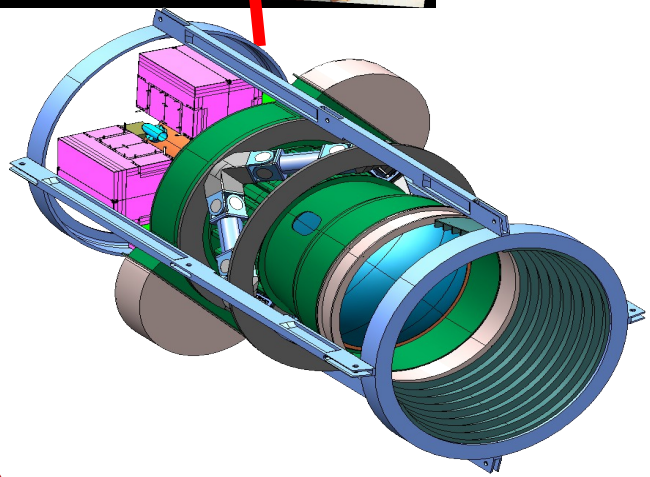
- Motivation and Description of Survey
- Victor M. Blanco 4m Telescope
- DES Camera
- DES Science



Dark Energy Survey (DES)

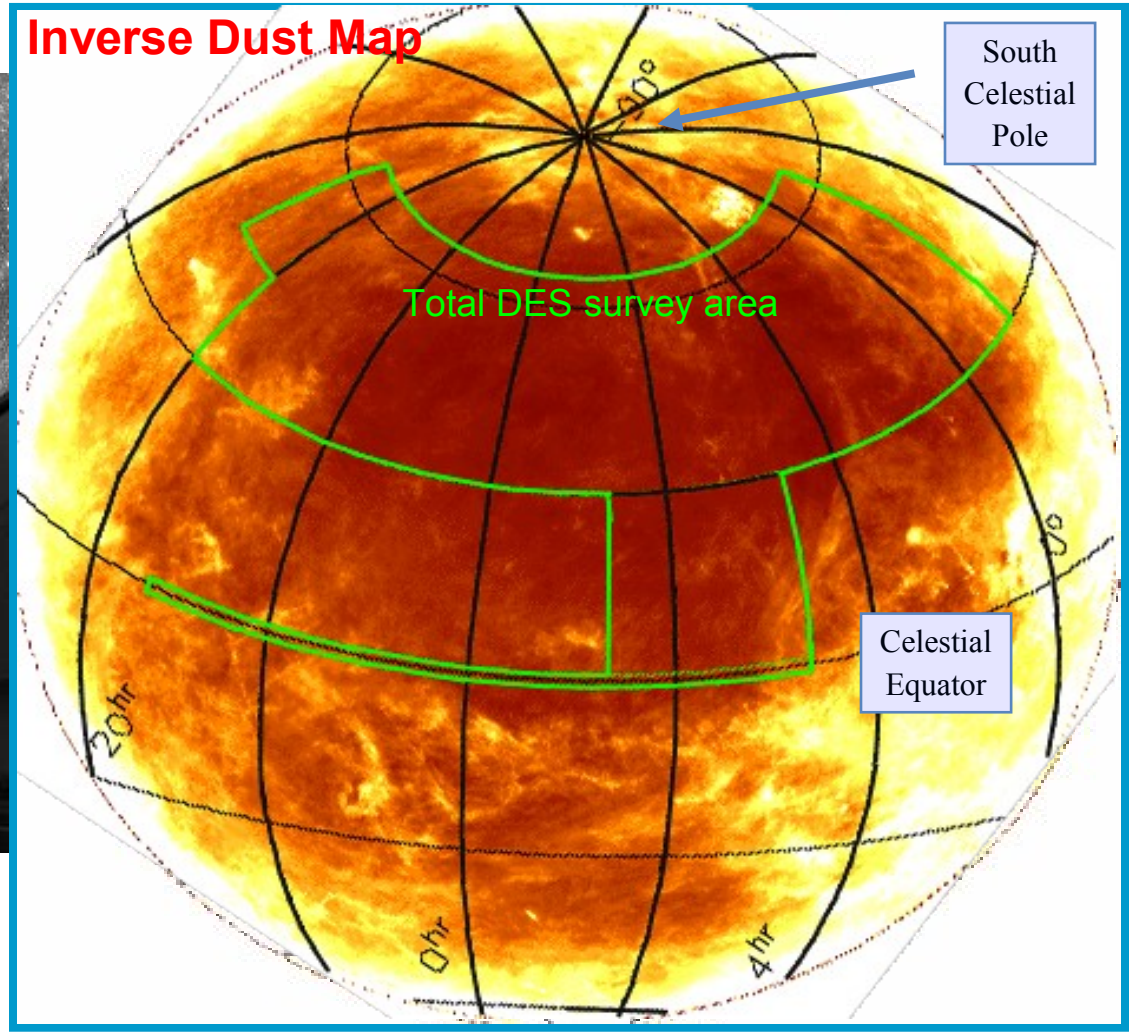
DES is providing a new 520Mpixel CCD camera (DECam) for an existing 4m telescope in Chile in exchange for 525 survey nights over 5 year period.

DES group at Argonne:
Joe Bernstein, Steve Kuhlmann, Hal Spinka, & Rich Talaga, plus engineers Vic Guarino & Allen Zhao



DES Survey Area (5000 sq. deg)

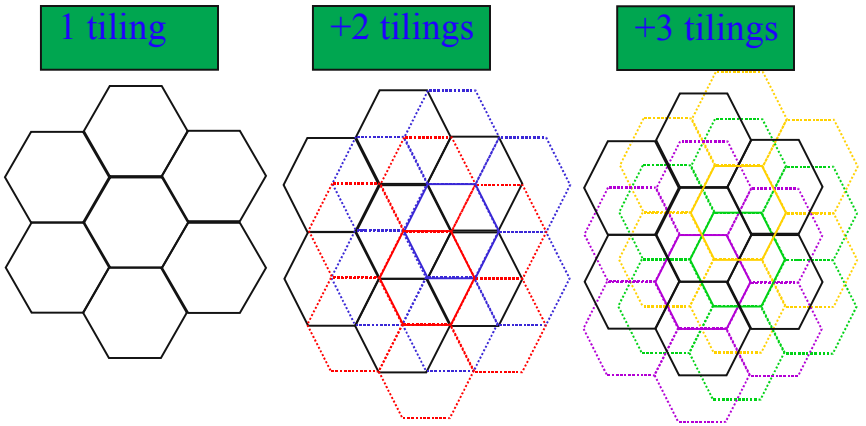
20 second exposure with 2Kx2K CCD by
Roger Smith/NOAO/AURA/NSF



Dark Energy Survey and Schedule

- Joint DOE/NSF project ~$40M
- FNAL, UC, UIUC, UK, LBNL, UM, OSU, Penn, Spain, Brazil 120 scientists
- First DES collaboration meeting in 2003
- ANL joined DES Feb 2007
- Fully-approved project (CD3)
- **Full-scale telescope simulator begins early in 2010, ~9 month test.**
- Delivery of camera to Chile Dec. 2010, first light 2011.
- John Peoples Project Director
- Brenna Flaugher Project Manager
- Darren Depoy Project Scientist

DECam 3 deg field of view (= 1 hex = 1 tile)



- **DES "tiles" 5000 deg of sky at a rate of 2 times per year in each of 4 filters, constraints on DE possible after two years**

Motivation I: New and Improved Sloan-like Survey

- Sloan Digital Sky Survey (~$80M) was extremely successful, most cited ground or space-based observatory. (>30000 citations so far)
- DES (~$40M) will use larger telescope, CCDs x4 more red-sensitive , and almost no overlap in survey coverage.

Motivation II: Redshifts for SPT

- South Pole Telescope will measure masses for thousands of galaxy clusters, with redshift-independent method.
- DES will overlap SPT survey area and provide redshifts for these clusters.

Glossary I

- AURA Association of Universities for Research in Astronomy, manages for NSF the Gemini Observatory, National Solar Observatory and NOAO, manages for NASA the Space Telescope Science Institute.
- NOAO National Optical Astronomy Observatory, funded by NSF, operates telescopes at Kitt Peak and CTIO as well as others
- CTIO Cerro Tololo Inter-American Observatory, operates several telescopes on Cerro Tololo including 4m Blanco
- Victor M. Blanco: Former director of CTIO
- Blanco Telescope: Commissioned in 1974 (~$5M), twin Mayall 4m telescope at Kitt Peak

Motivation III: 2003 AO for Blanco

- **Blanco 90% use last year, x2 more requests not met.**
- **During ~2 minute exposure locks on guide star, maintains alignment to <0.2 arcseconds.**
- **1 DES pixel=0.7 arcseconds**

CTIO

Announcement of Opportunity for a Blanco Instrumentation Partnership

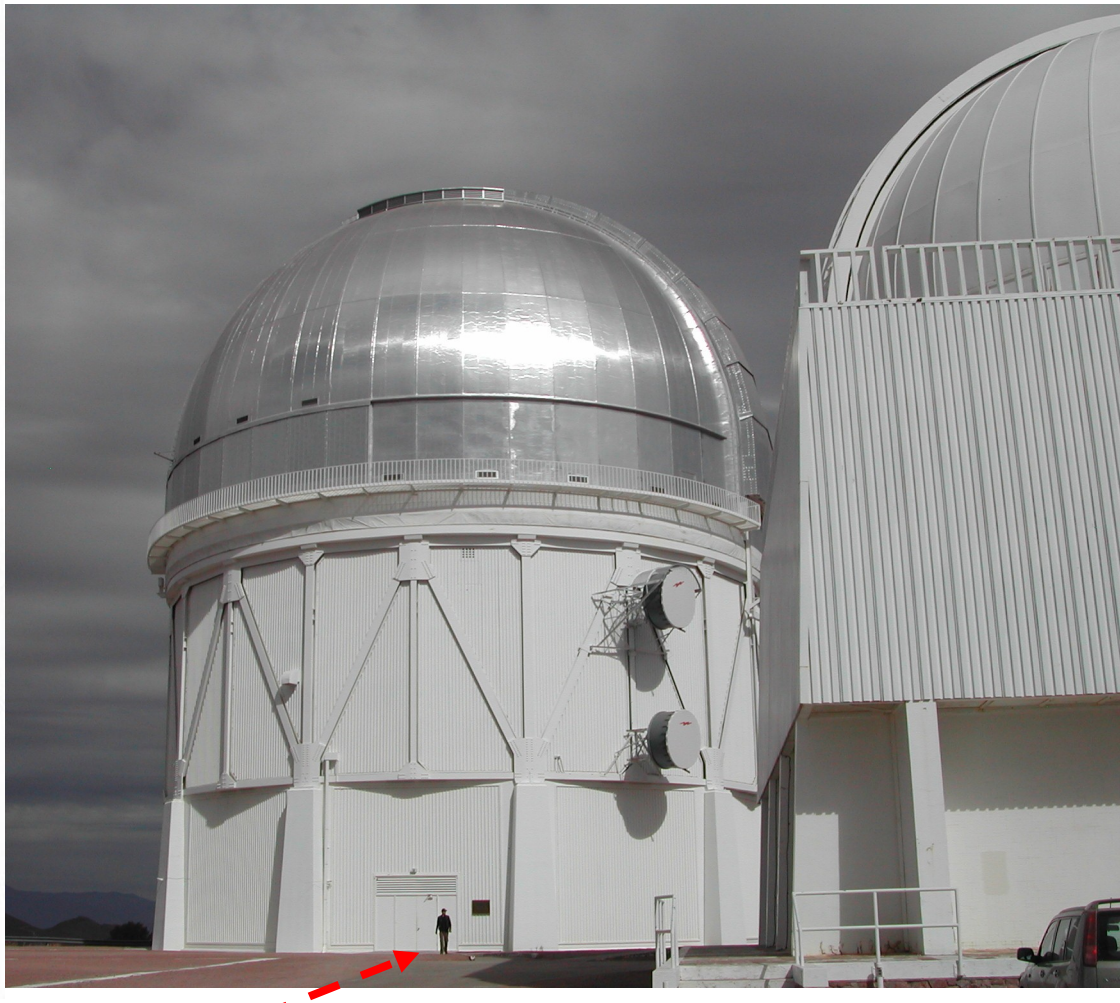
Alistair Walker

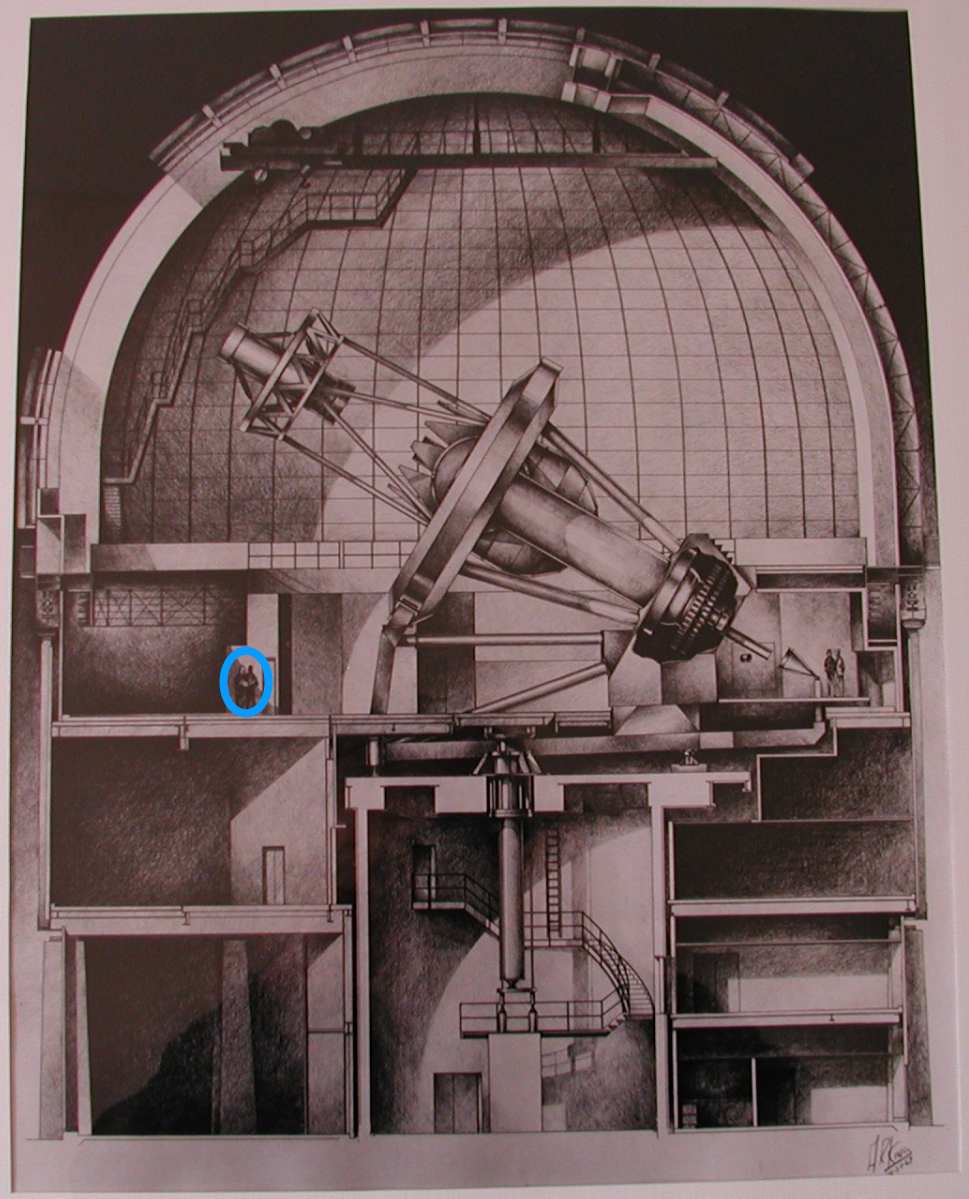
NOAO announces a partnership opportunity to develop a major new instrument for the Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory (CTIO). Although there are no restrictions on the type of instrument that can be proposed, we see a special opportunity to exploit the wide-field capability of the prime or RC foci of the telescope. Additionally, any proposed instrument should be consistent with a system-wide view of facilities available to the US community, in particular those in the southern hemisphere. Guidance on the US system can be obtained from the report on the first workshop on the ground-based optical/infrared (O/IR) system, at *www.noao.edu/gateway/oir_workshop/*.

The full Announcement of Opportunity, and links to descriptions of the Blanco telescope and its instrumentation, can be found at *www.ctio.noao.edu/telescopes/TheFuture/Blanco_prop.html*. By the likely time of the commissioning of the new instrument solicited here, we expect to have retired the RC and Echelle spectrographs, since their capabilities will have been replaced by new instrument in sufficient depth for peer reviewers to assess the feasibility of the project with the resources to be committed. The management plan should outline the proposed sharing of responsibilities for work packages covering optomechanical and focal plane design and development, data acquisition, and data management between the proposer and NOAO. A general management structure, along with a schedule of project reviews and acceptance testing, should be included. The management plan should also include a basic plan for educational and public outreach, and explain the broader impacts of the project.

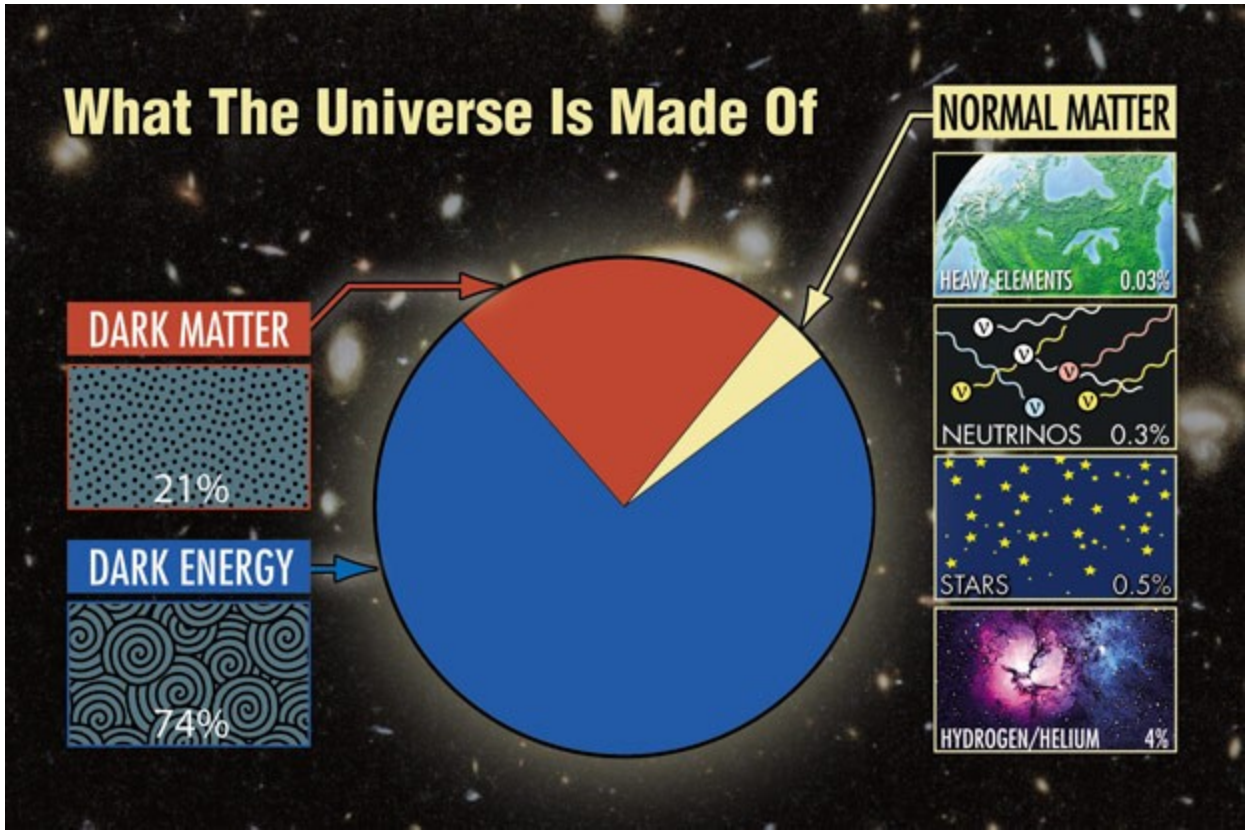
Up to 30 percent of Blanco telescope time for five years commencing in 2007 or 2008 is available for the science project. NOAO will contribute the operation of the telescope and an upgraded control system with a combined nominal annual value of $4 million at real-year prices. NOAO would expect to partner with the successful proposer in developing a data management system, including data acquisition, that is compatible with the National Virtual Observatory. The successful proposer can expect to work with an engineering interface at NOAO with optomechanical and other expertise.

Blanco 4m Telescope





Motivation IV: Missing 95% of Universe



Courtesy: http://hetdex.org

If Dark Energy is Cosmological Constant, vacuum energy prediction from particle physics theory is too large by 60 orders of magnitude!

(this assumes SUSY breaking at 1 TeV scale, 120 orders of magnitude discrepancy if relevant scale is Planck scale)

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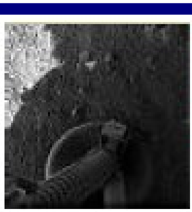
Flatow should have said "accelerated expansion confirmed"

Dark Energy Confirmed (broadcast Friday, December 19th, 2008)

This week researchers announced that they've confirmed the presence of dark energy in the universe -- a mysterious force that is pushing the expansion of the universe ever outwards. The new finding, ... astronomers using the ...-Ray Observatory, helps ... the universe got the way it is, ... it might end.

...ork trying to measure the ...ark energy examined supernovae, tracking the overall rate of expansion of the universe. The new work looks at a separate measure, the formation of structure within galactic clusters. Data from the two approaches agree, both confirming the presence of the force, and helping astrophysicists refine their calculations of its strength. Data from the new research also indicate that the ...

Abell 85, one of the galaxy clusters observed for the study, in X-ray and Optical wavelengths. X-ray(NASA/CXC/SAO/A.Vikhlinin et al.); Optical (SDSS)



SciFri Radio: 2008 Science News In Review

SciFri Video: Water Balloons in Space

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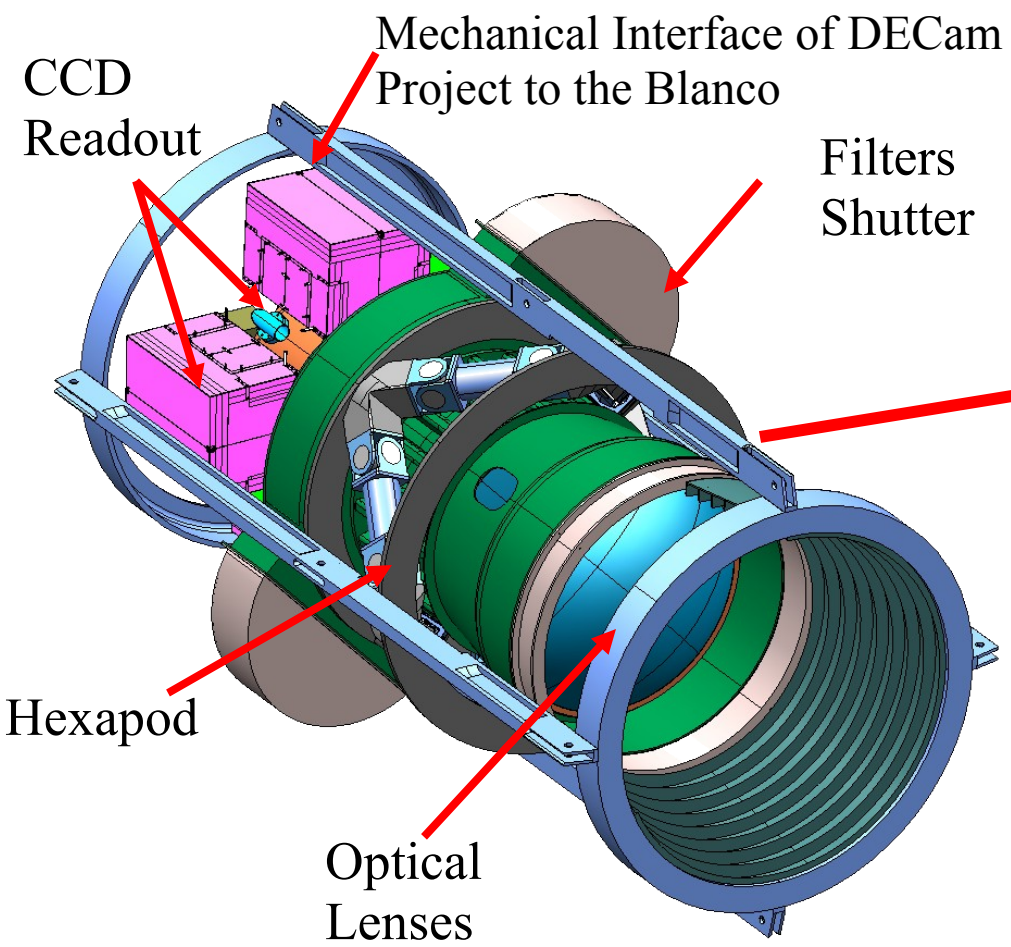
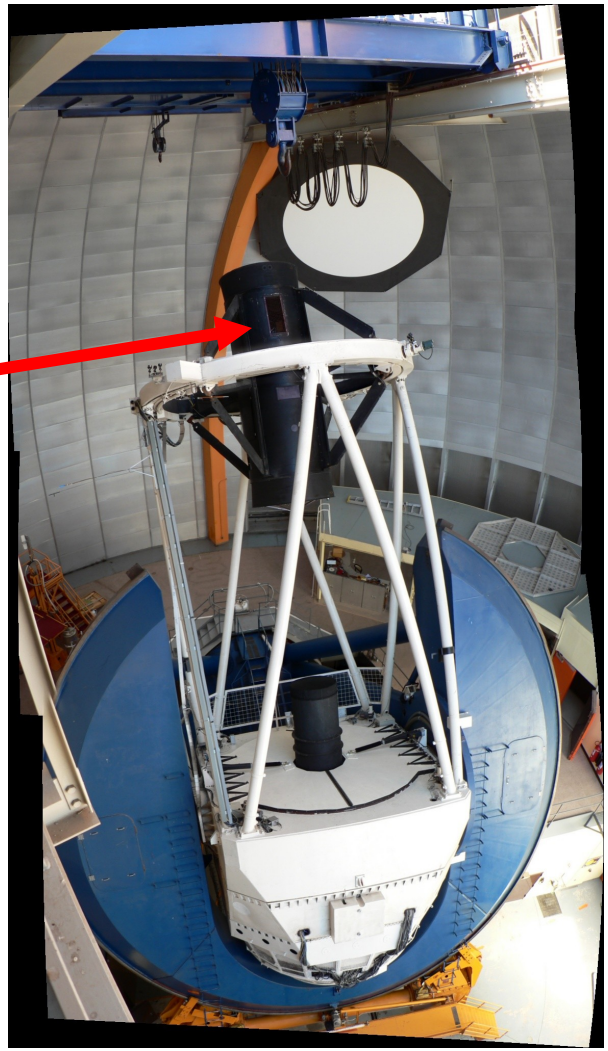
Thomas L. ...

The Omnivo...
Michael Pol...

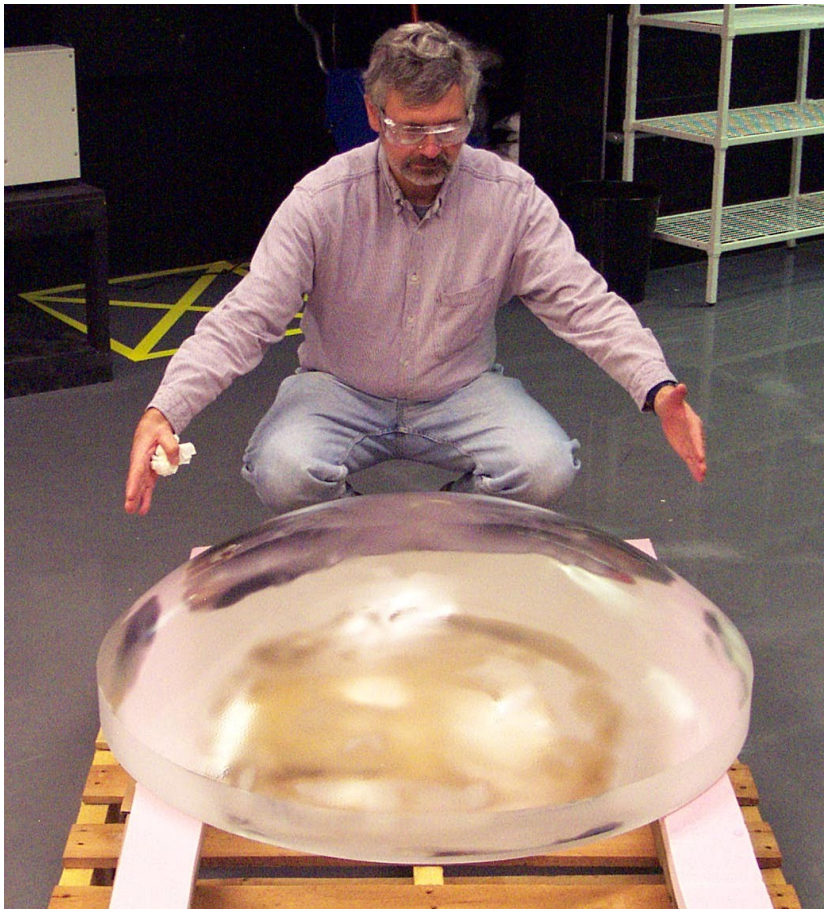
Based on Chandra X-Ray satellite measurements of galaxy clusters, independent of previous measures.

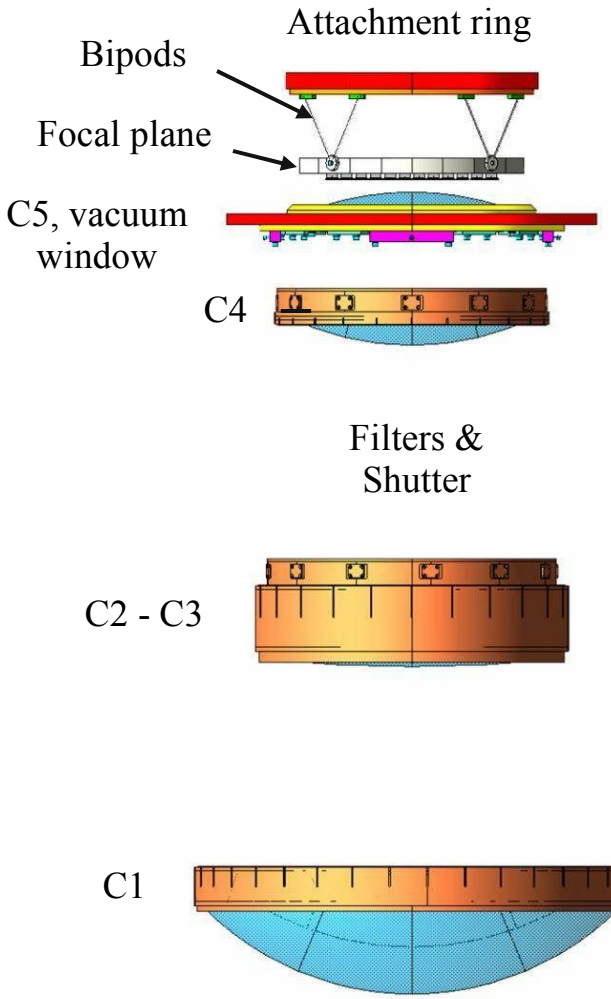
DES Camera


Mechanical Interface of DECam
Project to the Blanco
CCD
Readout
Filters
Shutter
Hexapod
Optical
Lenses



Optics
UK, Michigan, FNAL





DES Mechanical Engineering at ANL

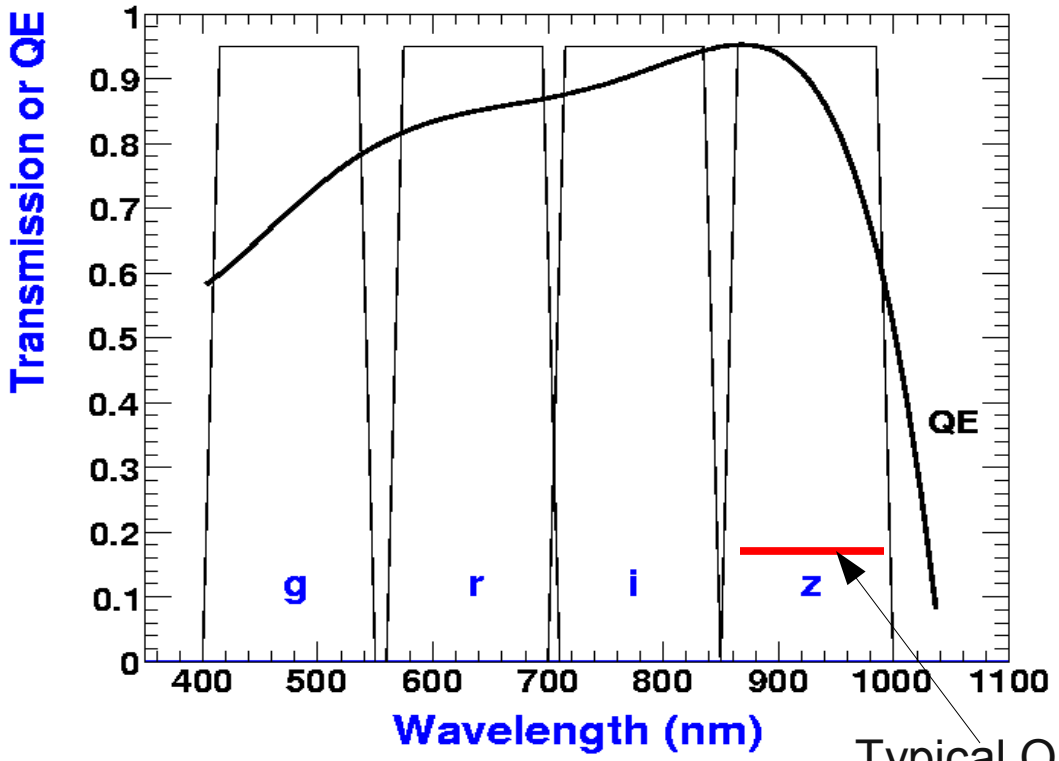
- L3 Manager Instrument Control System - Zhao/HEP
- Secondary mirror handling design - Zhao/HEP+Davis/NE
- Focal plane FEA – Guarino/HEP
- 5th lens cell – Bailey/NE
- Test-stand dewars – Guarino, Skrzecz/HEP
- Bulk of DES LDRD "buy-in" was 2 FTE engineering, finished in FY08. Expect ~3 FTE from FNAL DES project funds in FY09 and another ~3 FTE in FY10.

Secondary mirror handling system (1-ton mirror)

Alignment better than 300 microns and handling robust enough for earthquakes.

Filters and CCD Quantum Efficiency

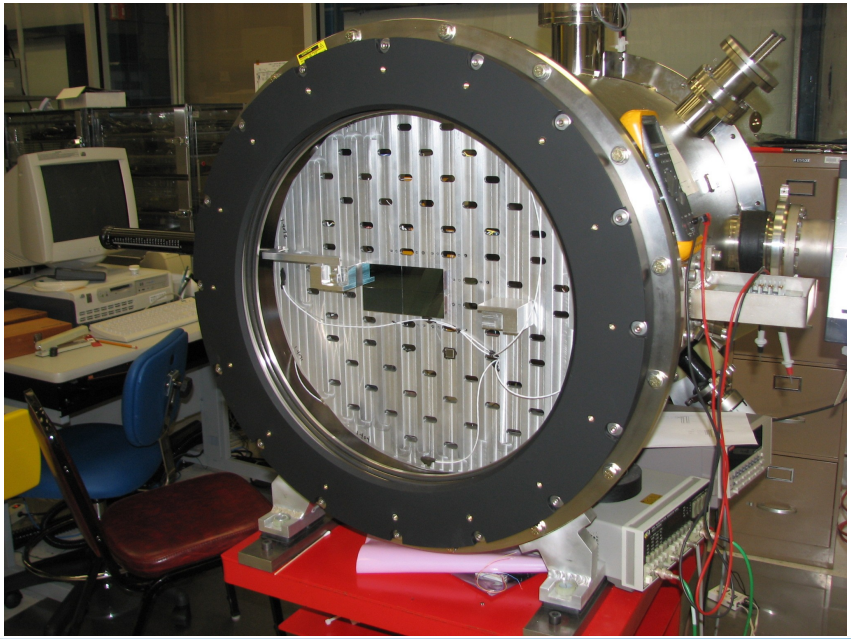
DES filters and QE, filters similar to SDSS

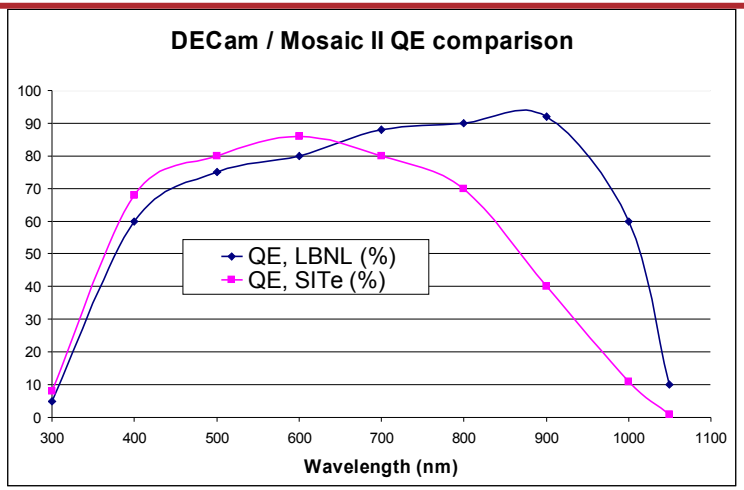


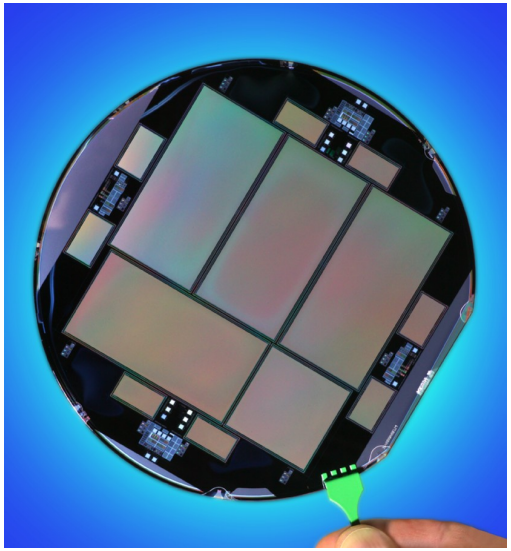
Typical QE of thin CCDs in z band. Big improvement in red QE with thick LBNL/SNAP/DES CCDs

DES CCDs (520 Mpixel total)

- Red Sensitive CCDs developed by LBNL:
  - QE> 50% at 1000 nm
  - 250 microns thick
  - readout 250 kpix/sec
  - 2 RO channels/device
  - readout time ~17sec



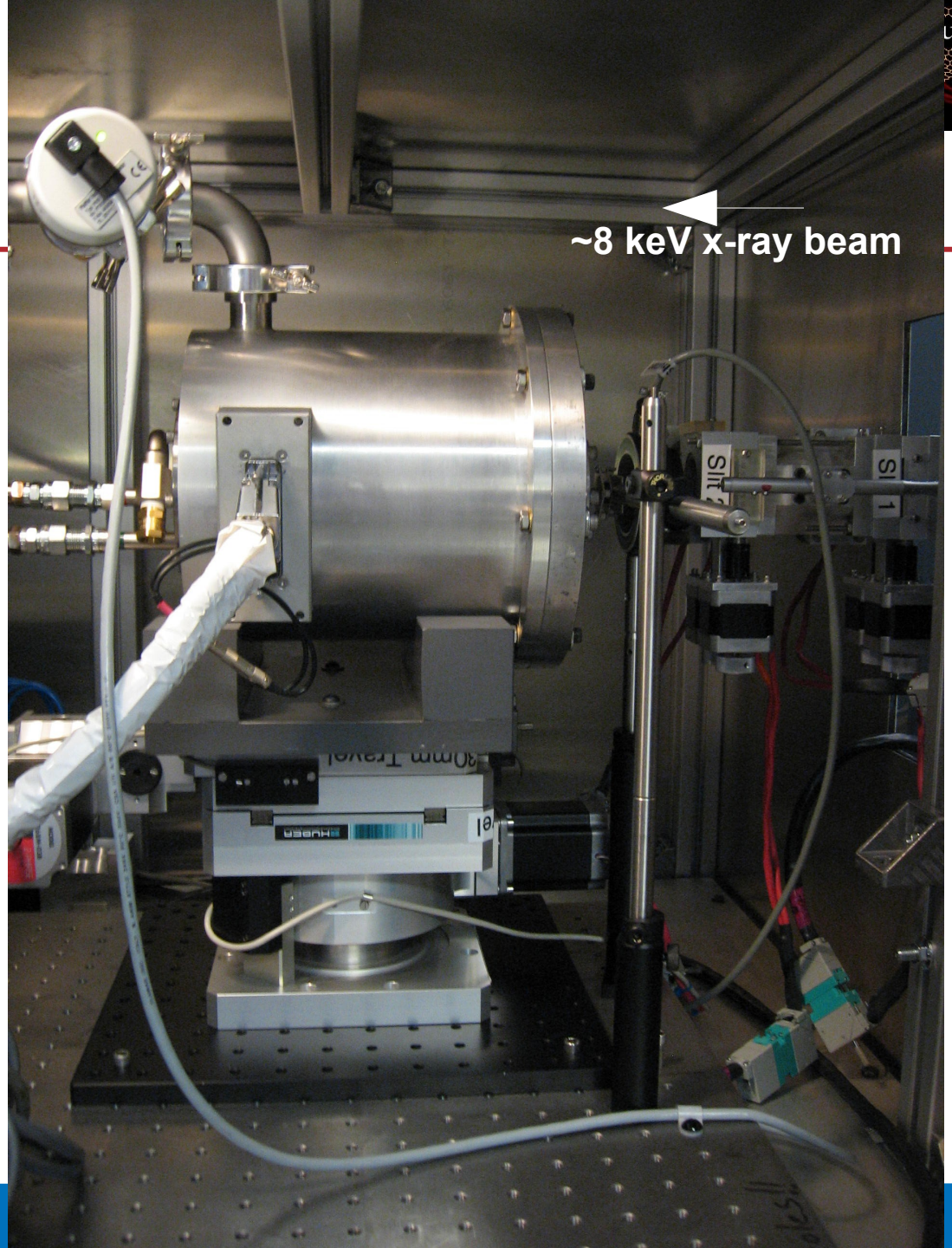


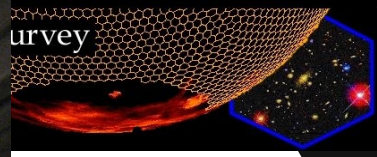


DES CCD Tests at ANL

HEP portable CCD test-stand taking data with DES CCD at APS x-ray lab.

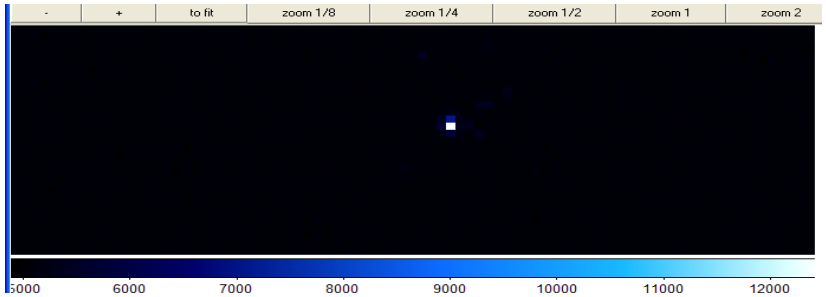
Using x-ray tube plus 5 μm tungsten pinhole, provides rare ~1-pixel beam.



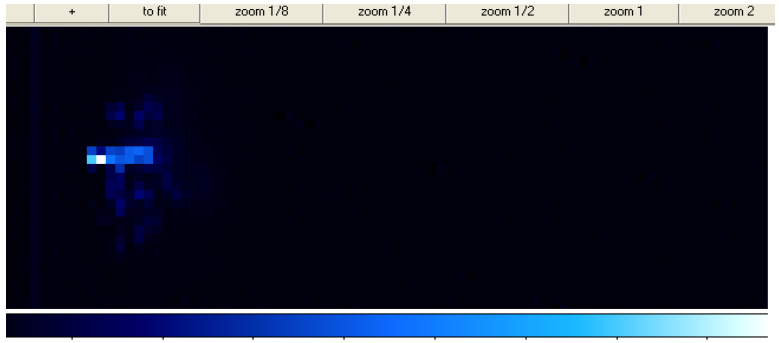


DES CCD Tests at ANL

Narrow beam away from CCD edge



Apparent diffusion near edge. Opposite of what FNAL experts expected! Studies resume next month.

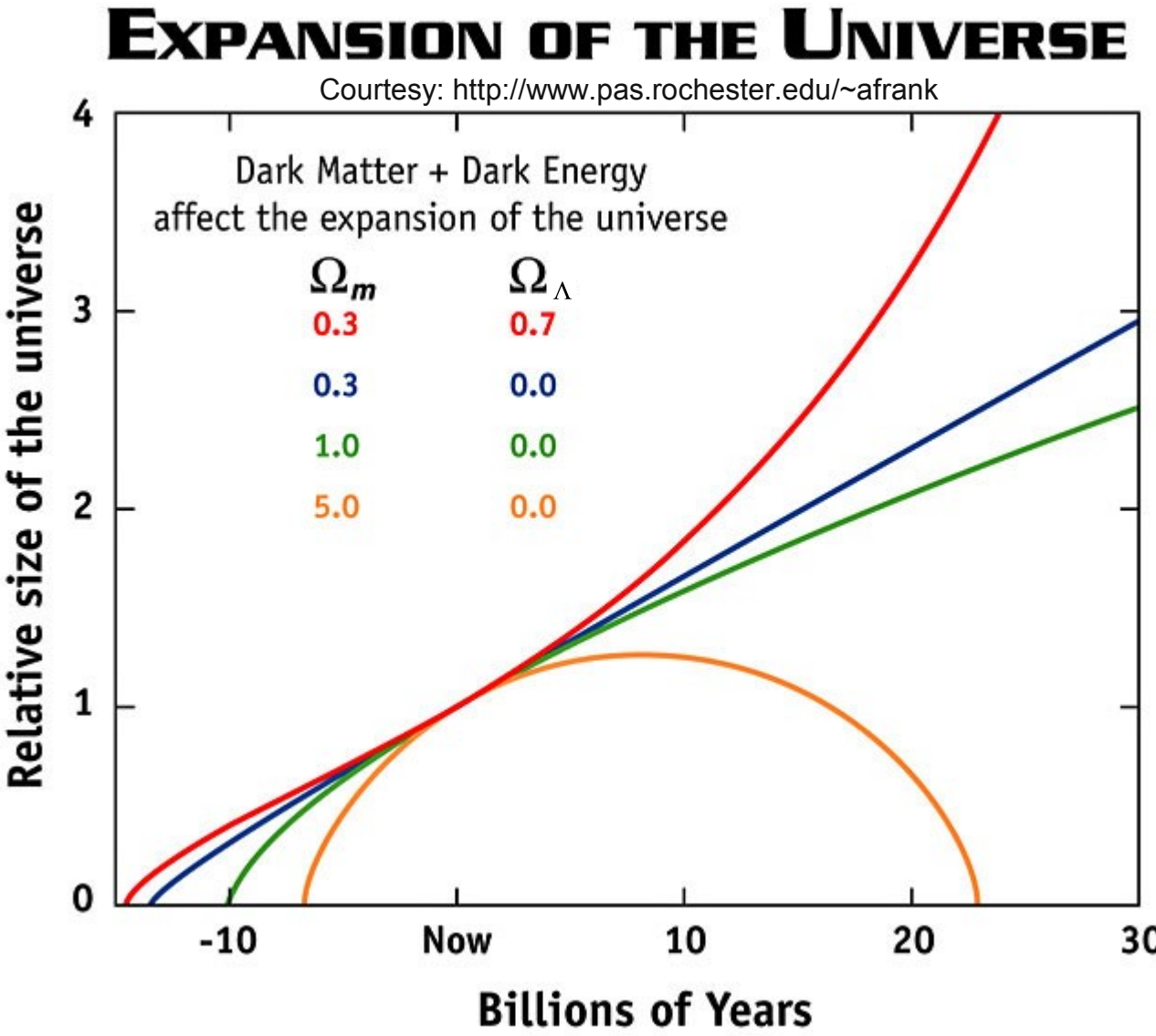


Evolution depends on energy density ρ

Define: $\Omega \equiv \rho/\rho_{crit}$

ρ_{crit}: matter density required to eventually halt the expansion of the Universe

Three main options for dark energy:
1) Cosmological Constant
2) New Scalar Fields
3) Modified gravity



Expansion Rate

$w = p/\rho$

$$\left(\frac{\dot{a}}{a}\right)^2 = H_0^2\left[\Omega_m a^{-3} + \Omega_r a^{-4} + \Omega_k a^{-2} + \Omega_{DE} a^{-3(1+w)}\right]$$

a(t) **is scale factor (size) of universe relative to now (*a(now)=1*)**

H_0 is Hubble constant, 72 km s^{-1} Mpc^{-1}

Ω_m is non-relativistic matter (0.27)

Ω_r is photons and relativistic neutrinos (10^{-4})

Ω_k is curvature (0 if flat universe)

Ω_{DE} (or Ω_Λ) is cosmological constant if $w = -1$ (0.73)

What is *w*? Is it time dependent *(w(a))*?

General Comments...

- Cosmic Microwave Background peaks + Hubble Constant give Ω_Λ=0.74 to 3% (astro-ph:0803.0547), but only a snapshot at one time thus minimal constraint on *w*

- Press releases claim ~6% measure of *w* when including Supernovae, true if *w* constant

- x3 worse if *w* evolves, measuring evolution is the main goal

- Common parameterization $w=w_0 + w_a (1-a)$

More Comments...

- Modified gravity unlikely to explain dark matter since effects on various scales from individual galaxies to CMB data.

- But certainly could have particle dark matter + modified gravity and no dark energy.

- Dark Energy Task Force focus was on evolution of *w,* their Figure of Merit is inverse area of w_a-w_0 error ellipse.

- New Figure of Merit Working Group was created for JDEM (next-generation space-based survey) with more emphasis on modified gravity.

DES Key Science Projects

Four Techniques

- Galaxy Clusters
- Weak Lensing
- Baryon Acoustic Oscillations
- Supernovae

Will start with the most mature technique, Supernovae

Supernova Basics

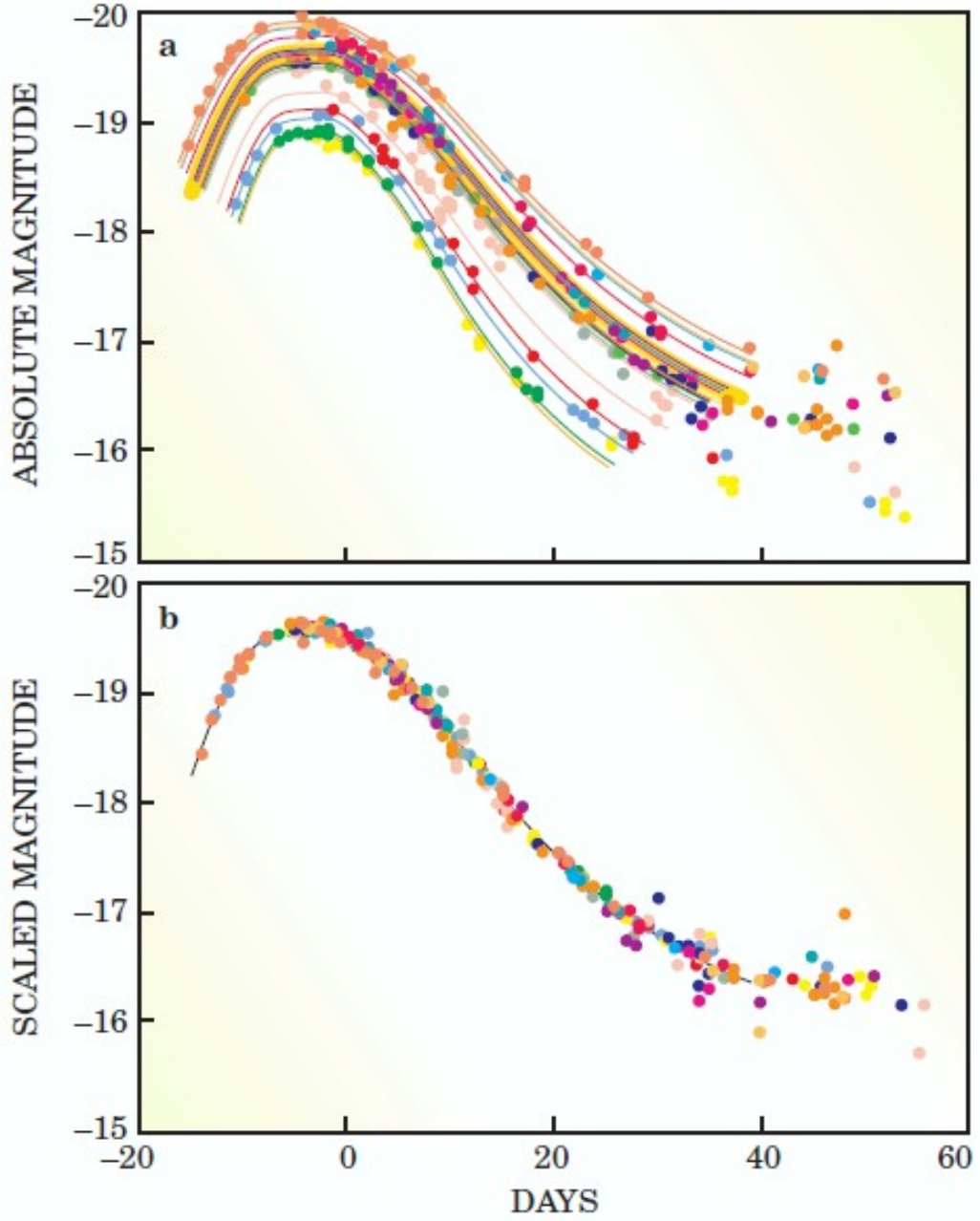
- Most common: exploding white dwarf due to accretion from companion
- z=1 SN exploded 8Gyears ago!
- x3 variation in absolute flux, but tightly coupled with width of light curve
- After width correction 15% variation remains. Need systematic shifts <3%.
- Typically sample a SN field every 5-6 days.

Supernova Basics

Observed magnitude:
$m=-2.5\log_{10}(\text{Flux})$

Absolute magnitude:
M=m if object at 10 parsec

Distance Modulus:
μ = Observed – Absolute
$\mu = 5\log_{10}(d/10\ \text{pc})$

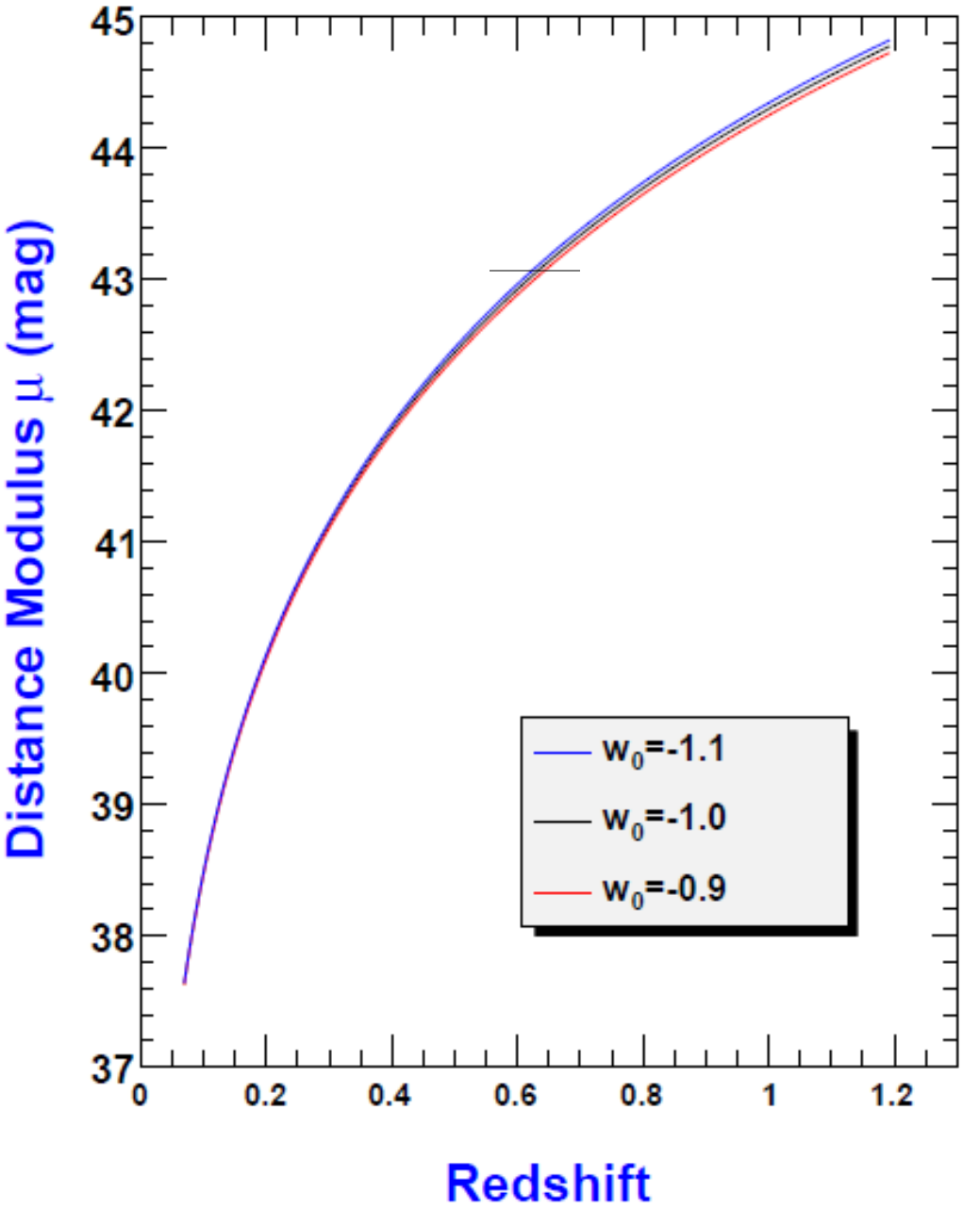


Supernova Basics

Distance Modulus:
μ = Observed – Absolute

DES observing limit
~24th magnitude,
SN absolute magnitude ~ -19,
Observed-absolute = $\mu \sim 43$

Beyond redshift 0.6 DES will not be fully efficient and will need corrections.



"Discovery Supernovae"

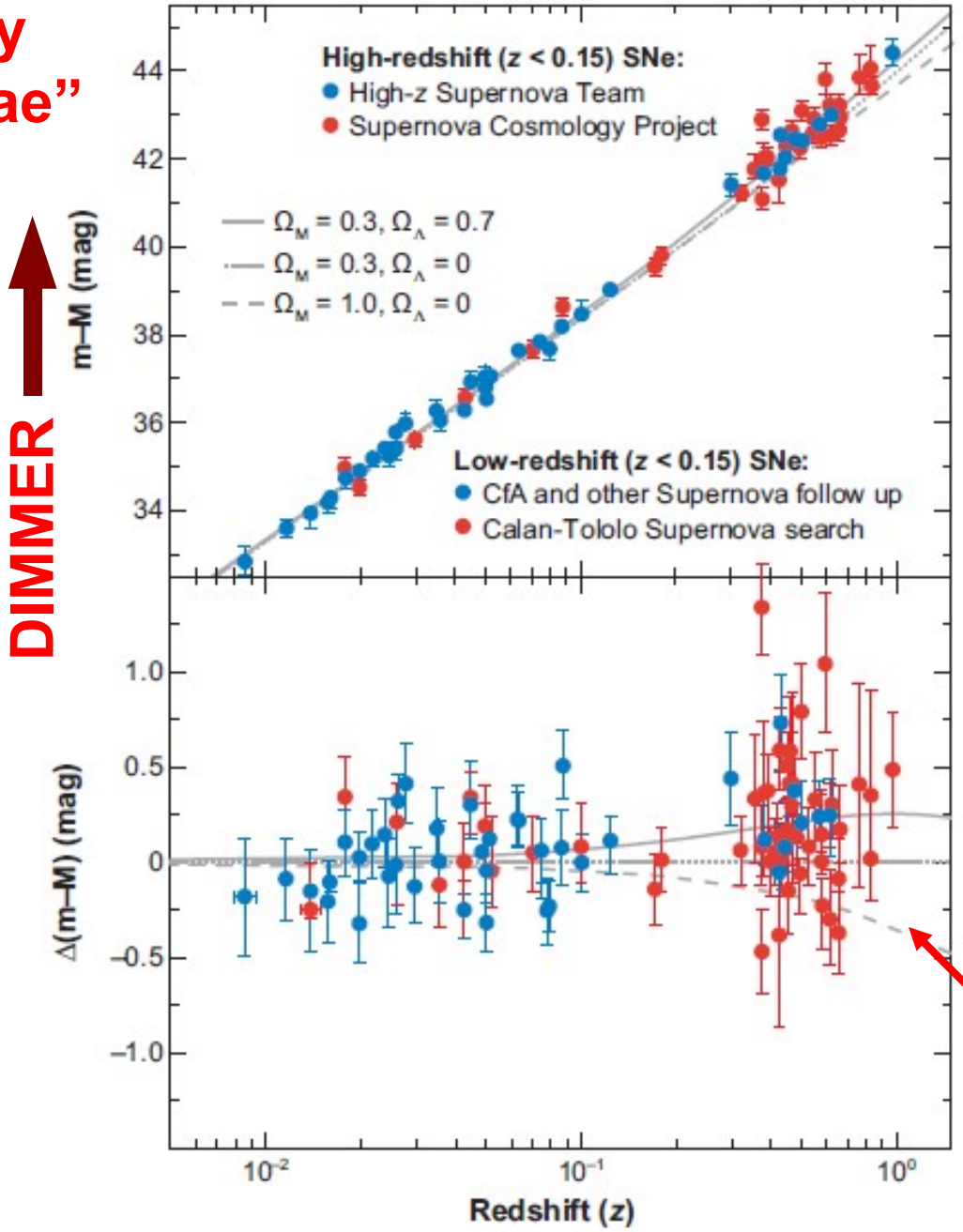


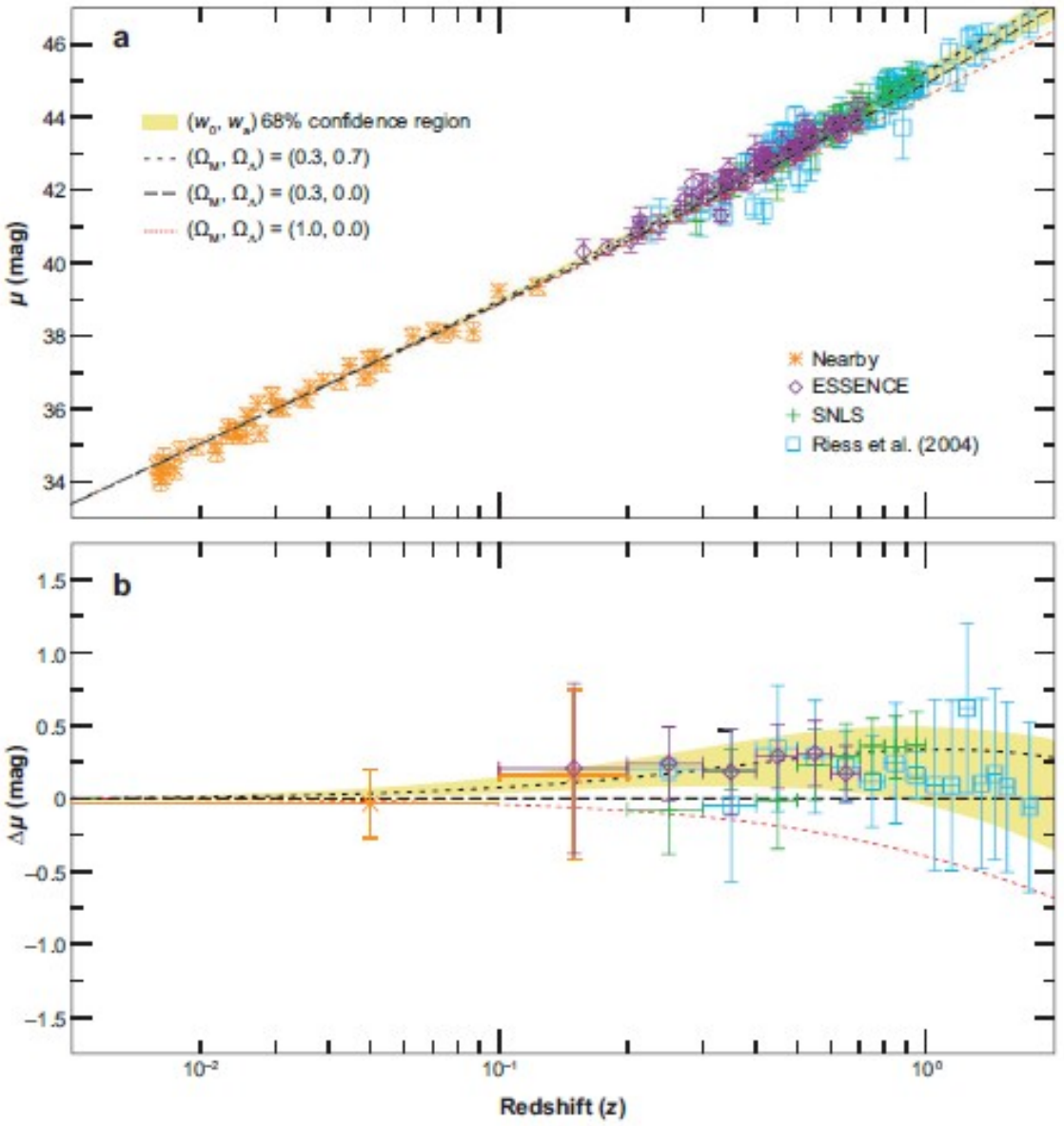
Figure 4

Discovery data: Hubble diagram of type Ia supernovae (SNe Ia) measured by the Supernova Cosmology Project and the High-*z* Supernova Team. *Bottom*: Residuals in distance modulus relative to an open universe with $\Omega_0 = \Omega_M = 0.3$. Figure adapted from Perlmutter & Schmidt (2003) and Riess (2000), based on Riess et al. (1998) and Perlmutter et al. (1999).

ANL DES group working closely with 3 members of these teams.

NO DE

Recent Supernovae Experiments



ANL Group and Supernova Science

- Joe Bernstein is leading the DES Supernova Strategy paper.

- ANL accepted for membership by SDSS supernova group. Much remains to be done for SDSS, only 103 of 1700 SN are part of current paper, and many systematic effects found.

- Simulation tools developed for DES naturally apply to LSST(next generation ground-based telescope). Accepted into LSST Supernova Science collaboration, will ramp up after DES paper is finished.

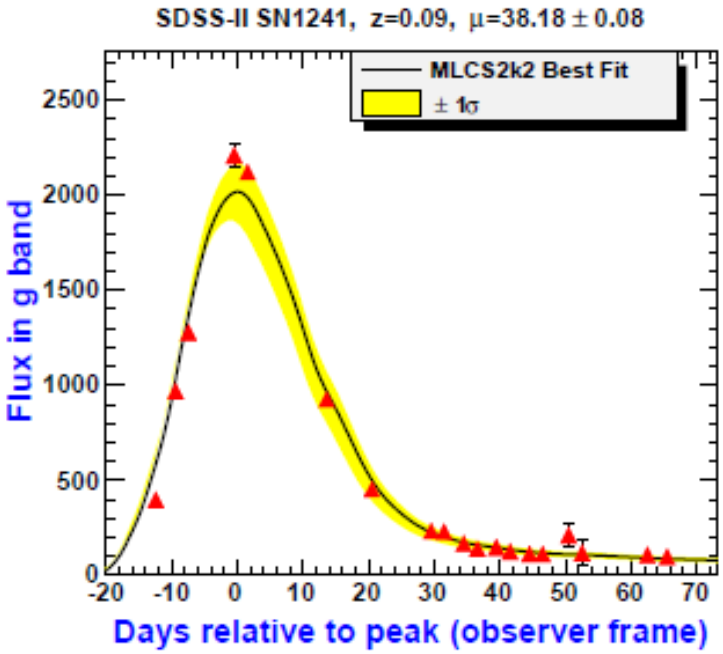
- Providing information to JDEM on DES capabilities (suggestion of joint JDEM-DES supernova program)

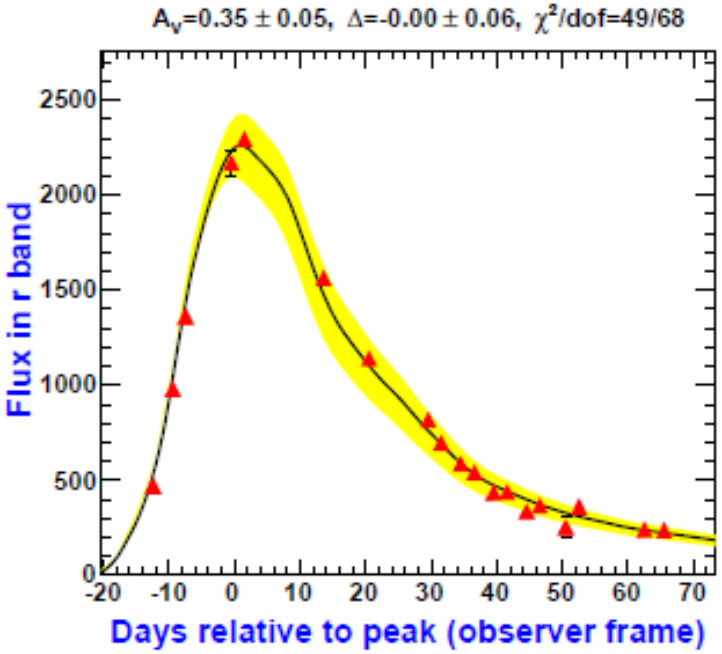
Supernova Light Curve Models

- MLCS2k2 (Jha, Riess, Kirshner 2007, ApJ, 659, 122) fit parameters:
  - epoch of maximum light
  - distance modulus (=observed magnitude – intrinsic magnitude)
  - luminosity/light curve shape parameter
  - extinction in magnitudes by host galaxy dust

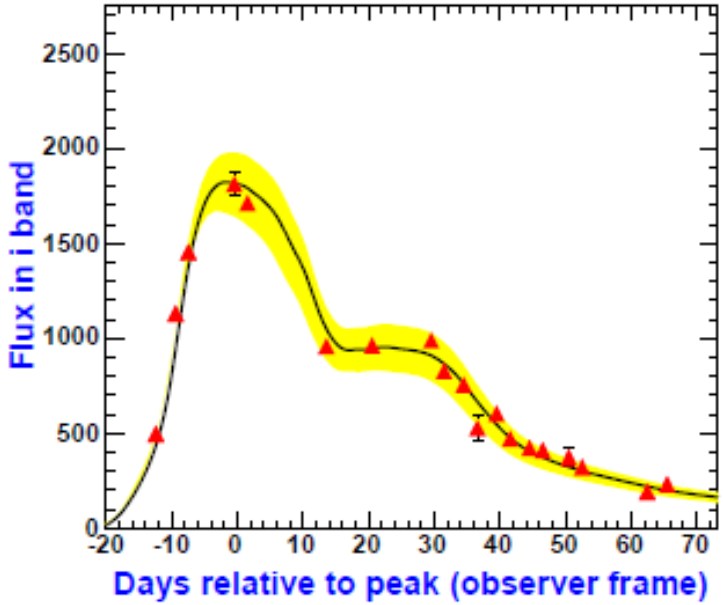
- SALT2 (Guy et al. 2007, ApJ, 466, 11) fit parameters:
  - Overall normalization
  - Quantity close to “stretch”
  - Color term includes dust and intrinsic SN color

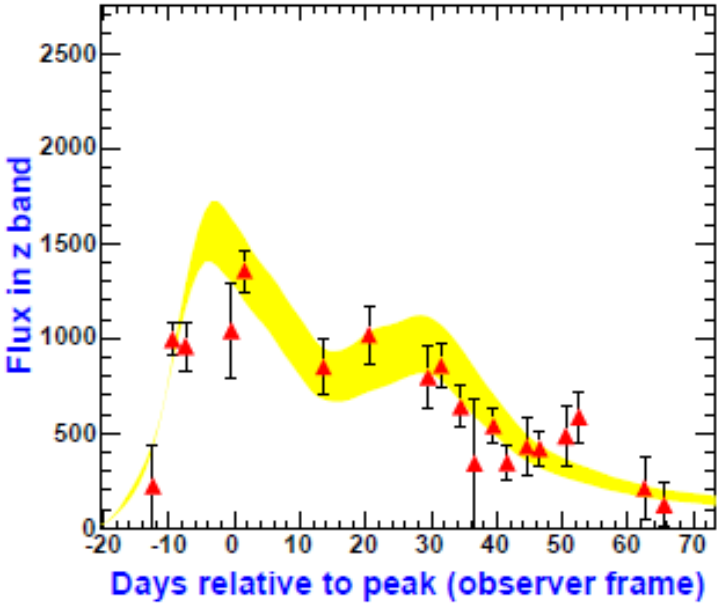
- Different philosophies, MLCS fits individual SN while SALT fits binned SN for average distance modulus and best-fit cosmology





SDSS DATA, z=0.09





Second Bump in Type 1a SN

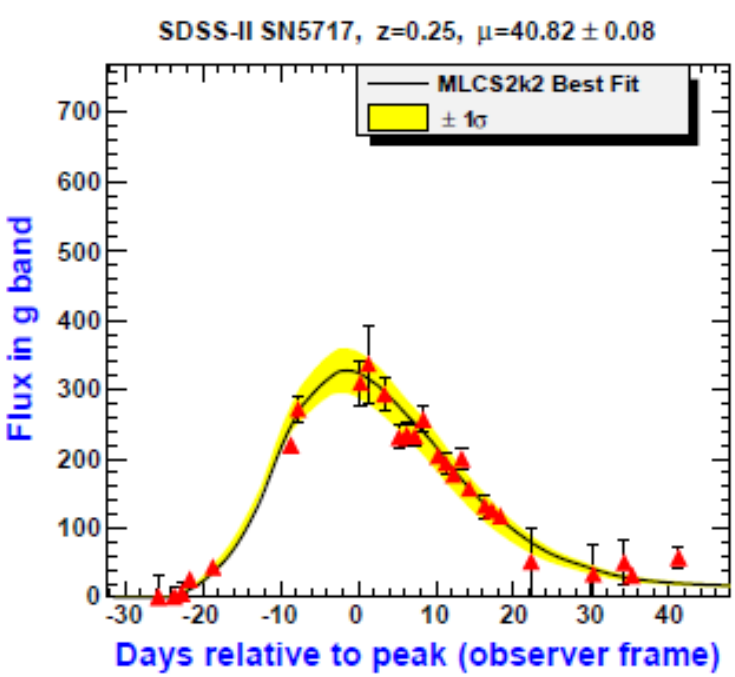
SECONDARY MAXIMUM IN THE NEAR-INFRARED LIGHTCURVES OF TYPE IA SUPERNOVAE

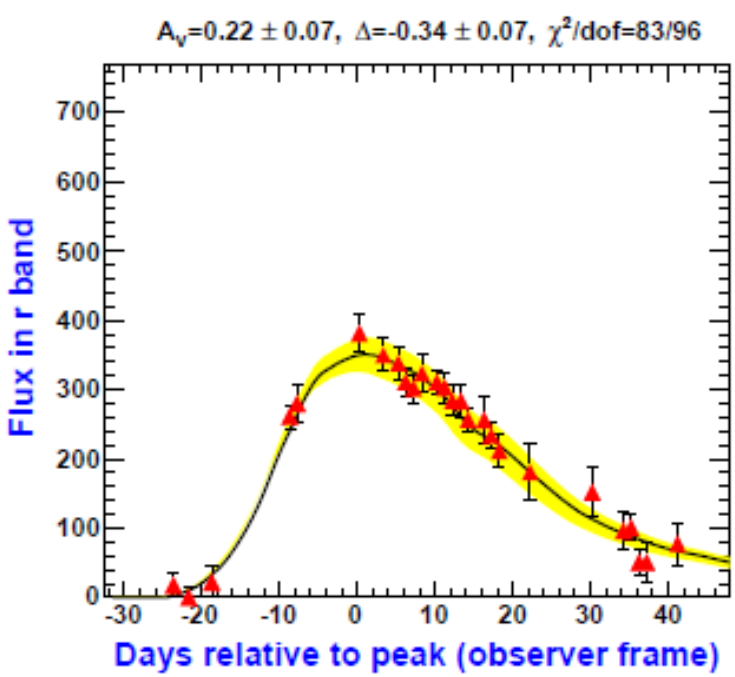
Daniel Kasen[1,2]

Draft version September 12, 2007

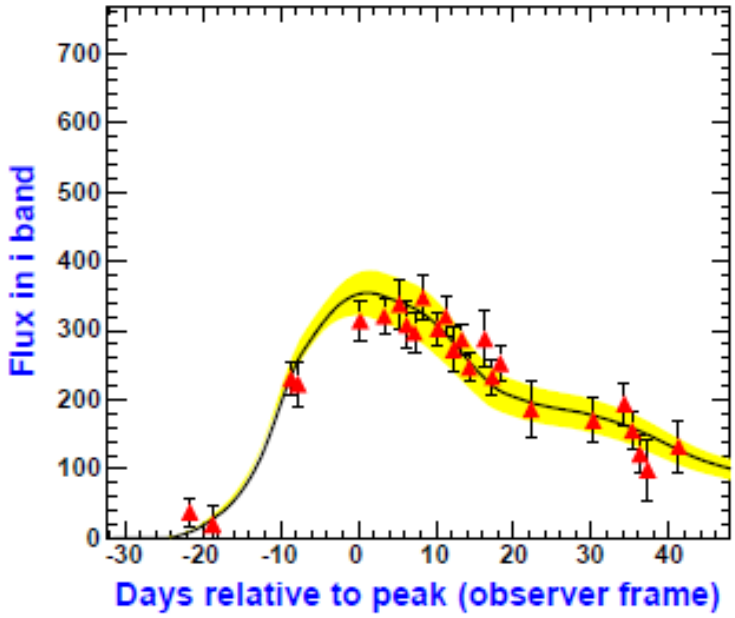
APJ 649, 2006

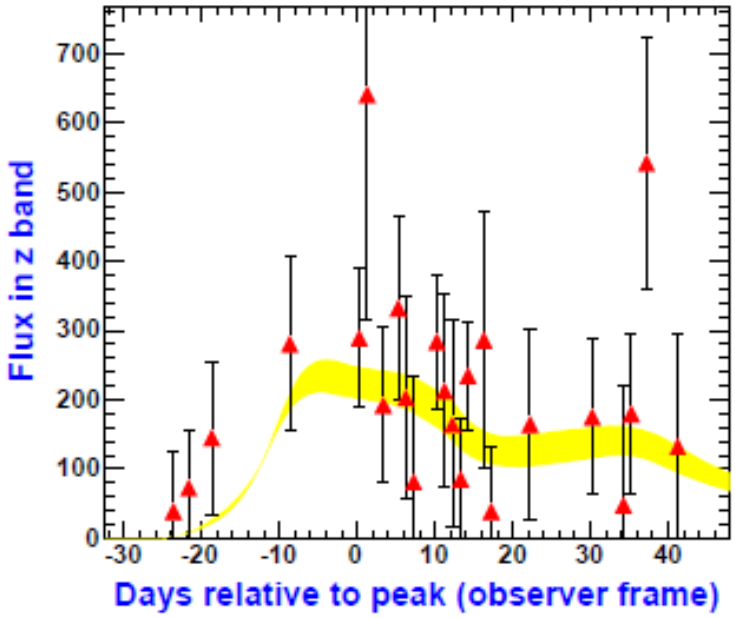
We trace the origin of the secondary maximum directly to the ionization evolution of iron group elements in the ejecta. Specifically, the NIR emissivity of iron/cobalt gas peaks sharply at a temperature $T_{21} \approx 7000$ K, marking the transition between the singly and doubly ionized states. The recombination of iron-rich gas from $2 \rightarrow 1$ thus leads to enhanced redistribution of radiation from blue to NIR. Interestingly, as the supernova cools, the



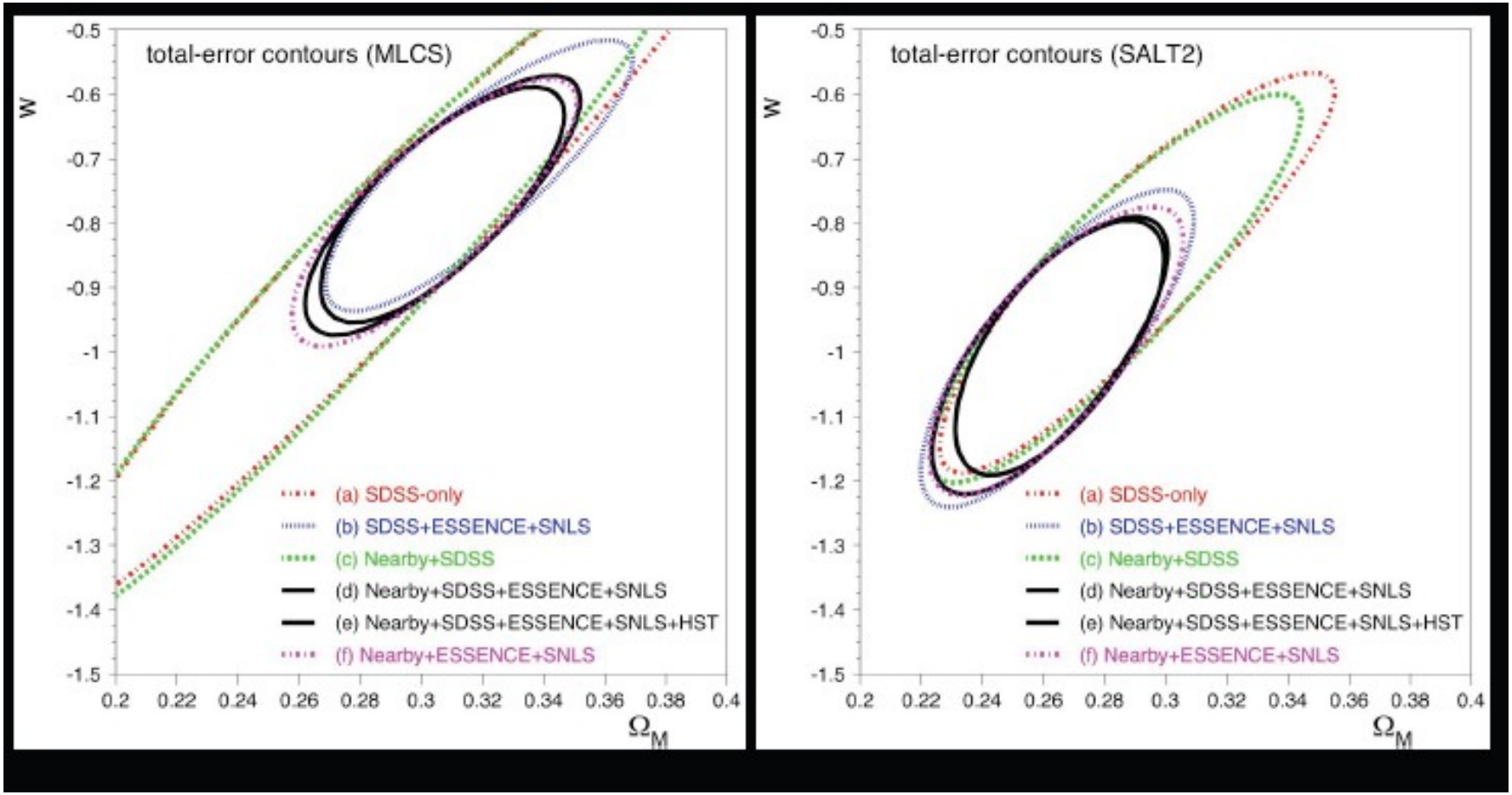


SDSS DATA, z=0.25





Preliminary SDSS results (103 SN), Fitter Dependence



Needs a lot of work and better training samples

Current Favored DES *Supernova* Fields

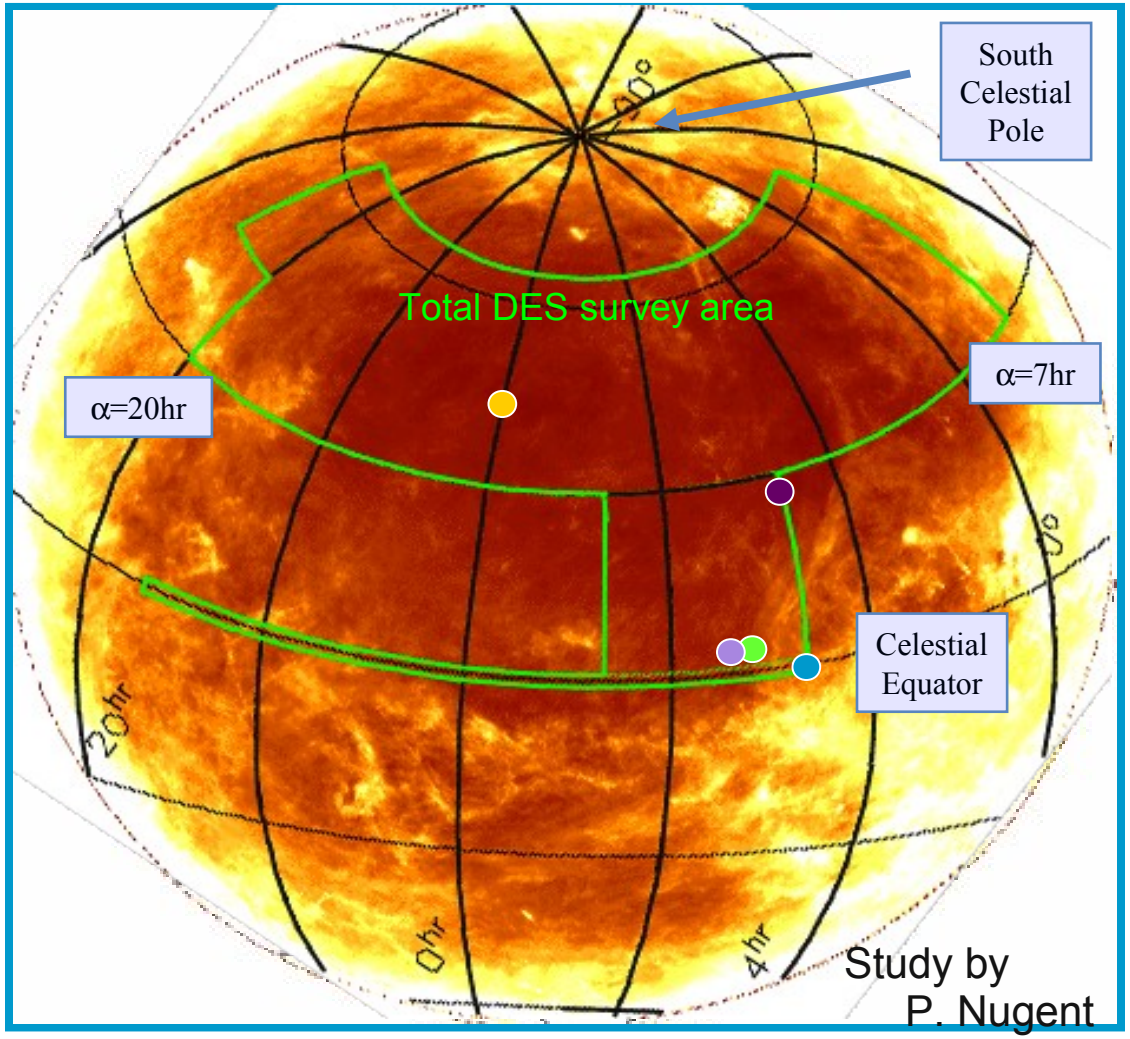
- Chosen to maximize:
  - visibility from DES site
  - past observation history
  - visibility from, e.g, Hawaii
  - potential overlap with VISTA IR survey

Chandra Deep Field – South
Sloan Stripe 82
SN Legacy Survey (SNLS) D1
XMM-Newton LSS
ELAIS S1

Hybrid strategy

2 deep fields with 2 hr exposure time each

3 shallow fields with 40 min exposure time each

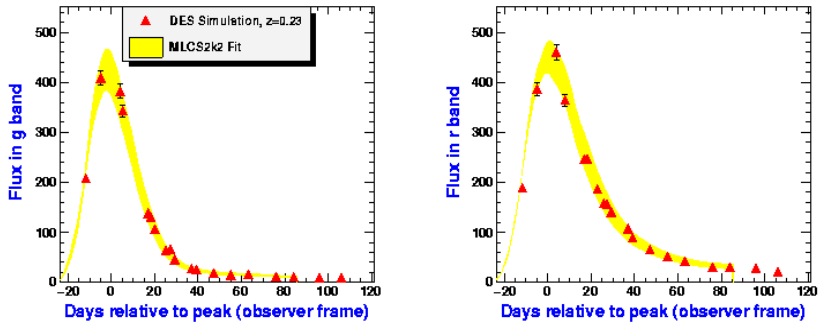


SNANA Software Package for DES

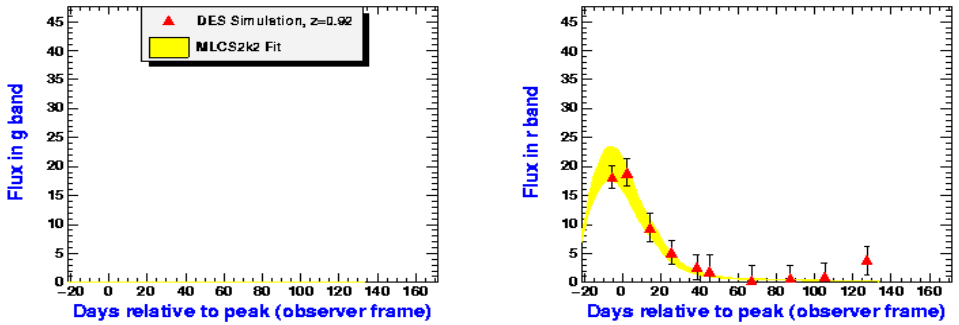
R. Kessler (U. Chicago), J. P. Bernstein, S. Kuhlmann, & H. Spinka (ANL)

- Software suite for simulating and fitting SN light curves, also used by SDSS and LSST
- Publicly available: http://www.hep.anl.gov/des/snana_package
- Simulation steps:
  - Generate rest-frame luminosity and fluctuations
  - Apply host galaxy dust extinction
  - Redshift correction
  - Apply Milky Way dust map based on trajectory
  - Apply CTIO weather history effects, sky noise including distance to the moon, and detector effects

Simulated DES Light Curves



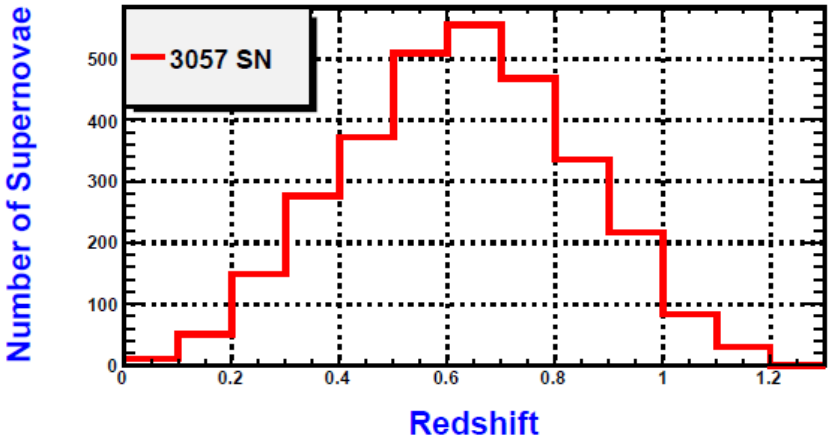
z=0.23

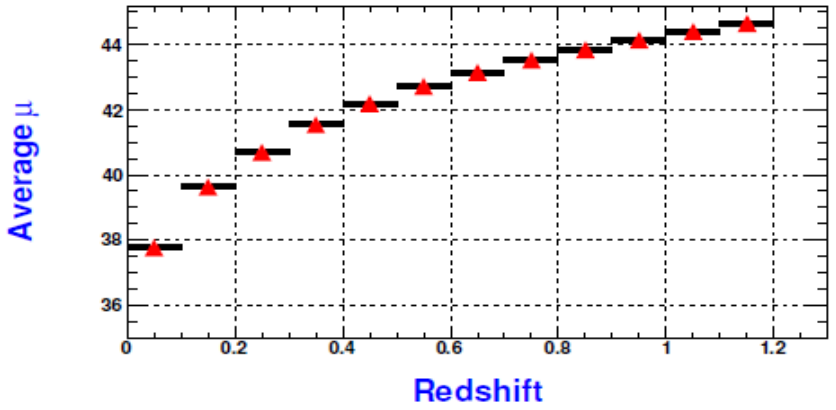


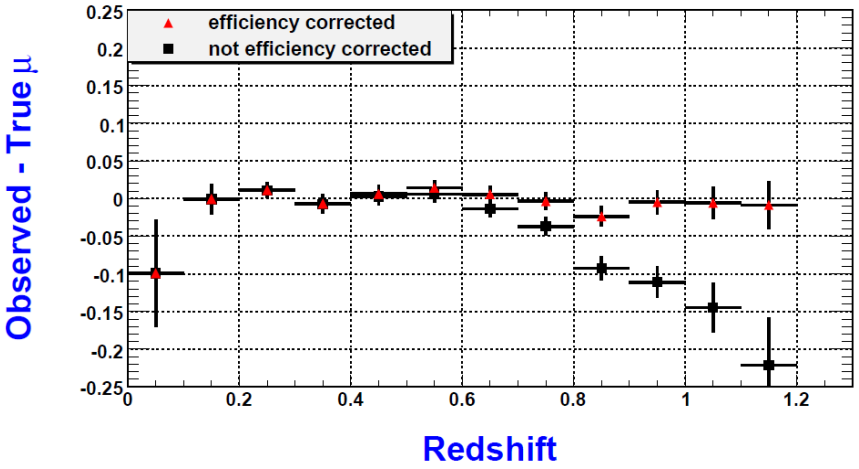
z=0.92

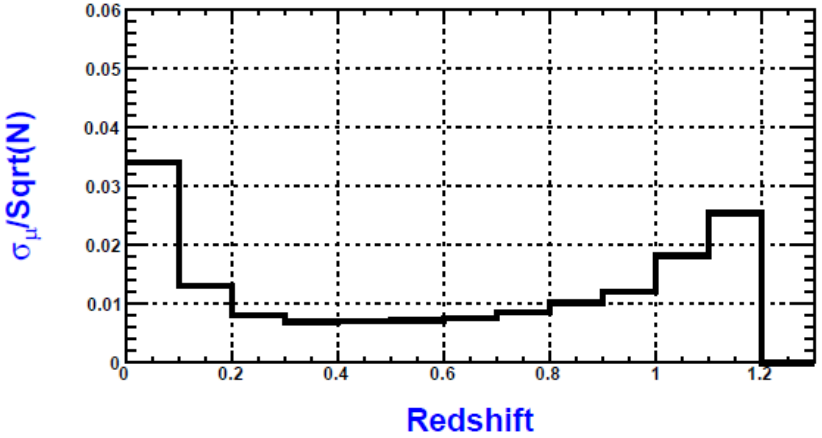
Default Survey: Hybrid griz

Cuts of 1 filter > 10 S/N and any 3 > 5 S/N have been applied for the griz filter set

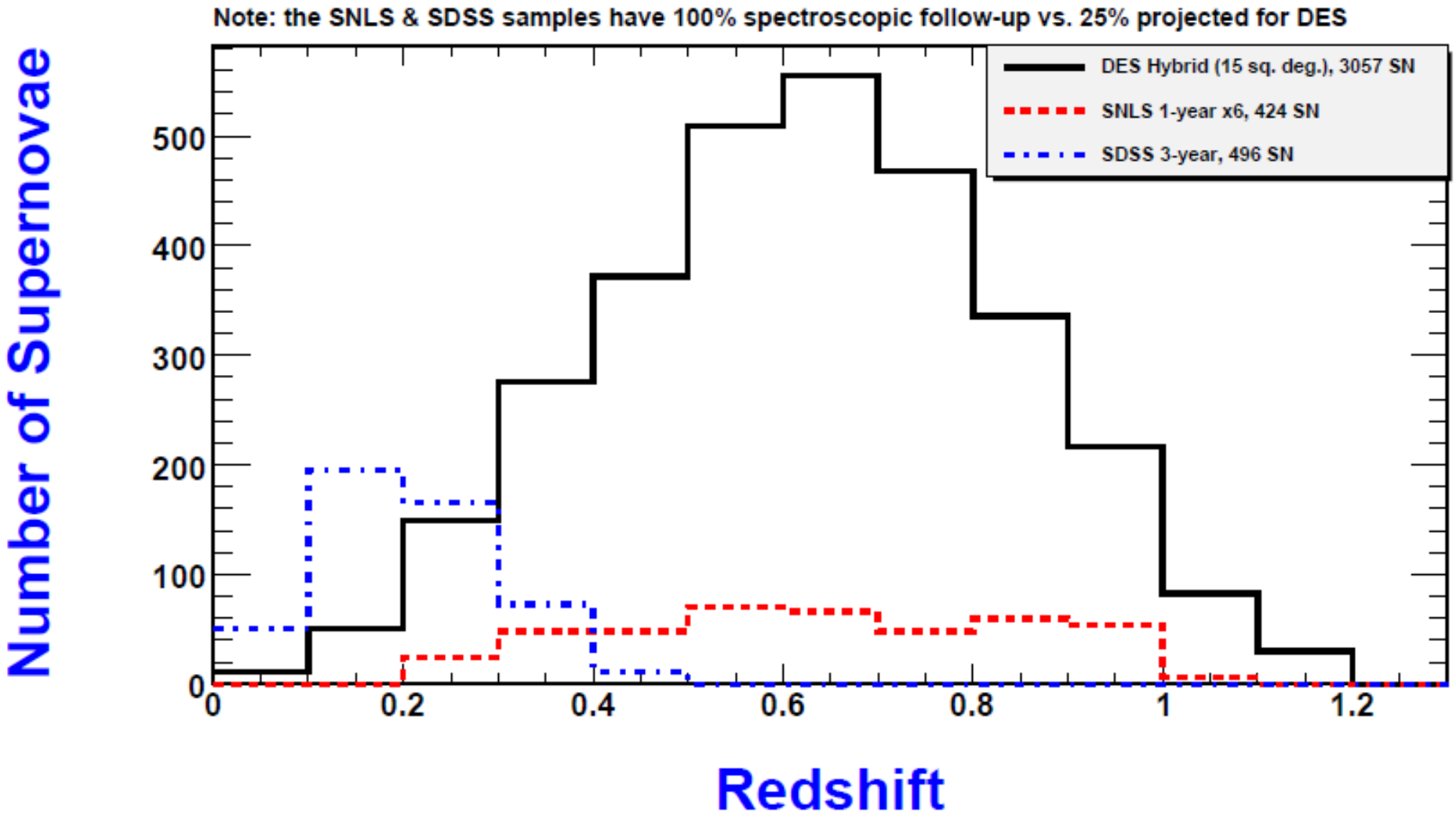




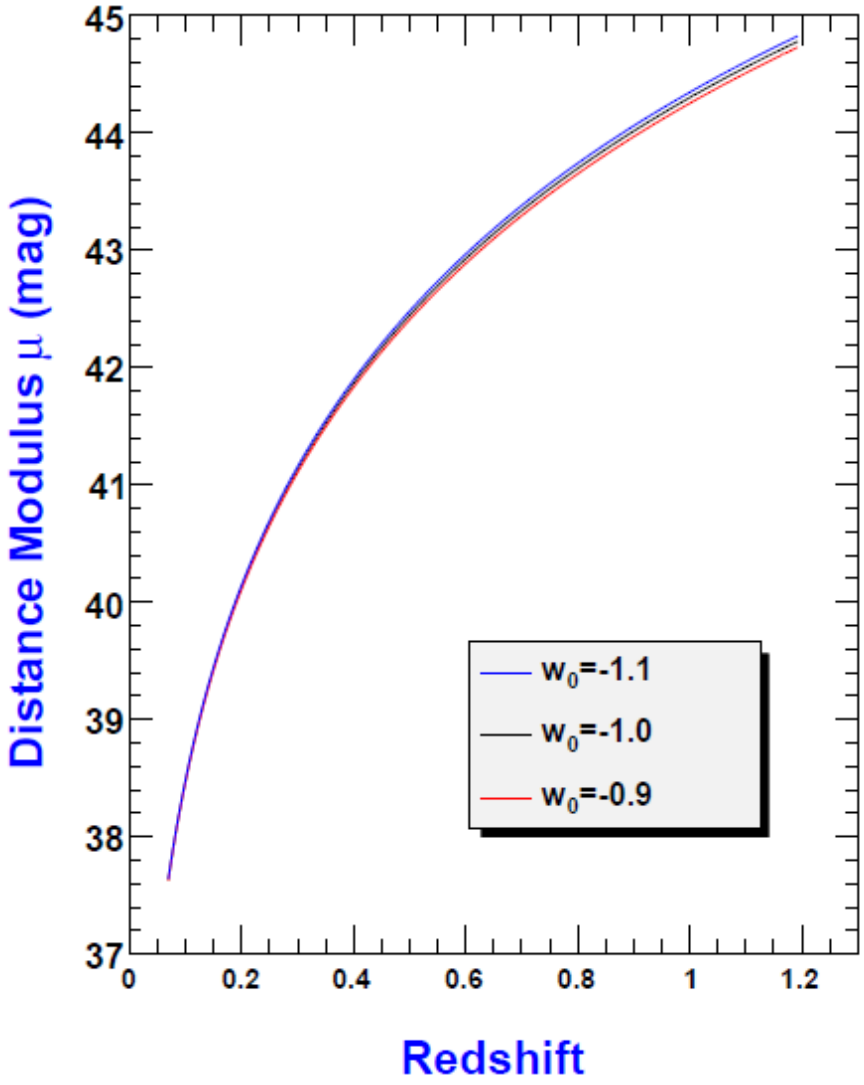


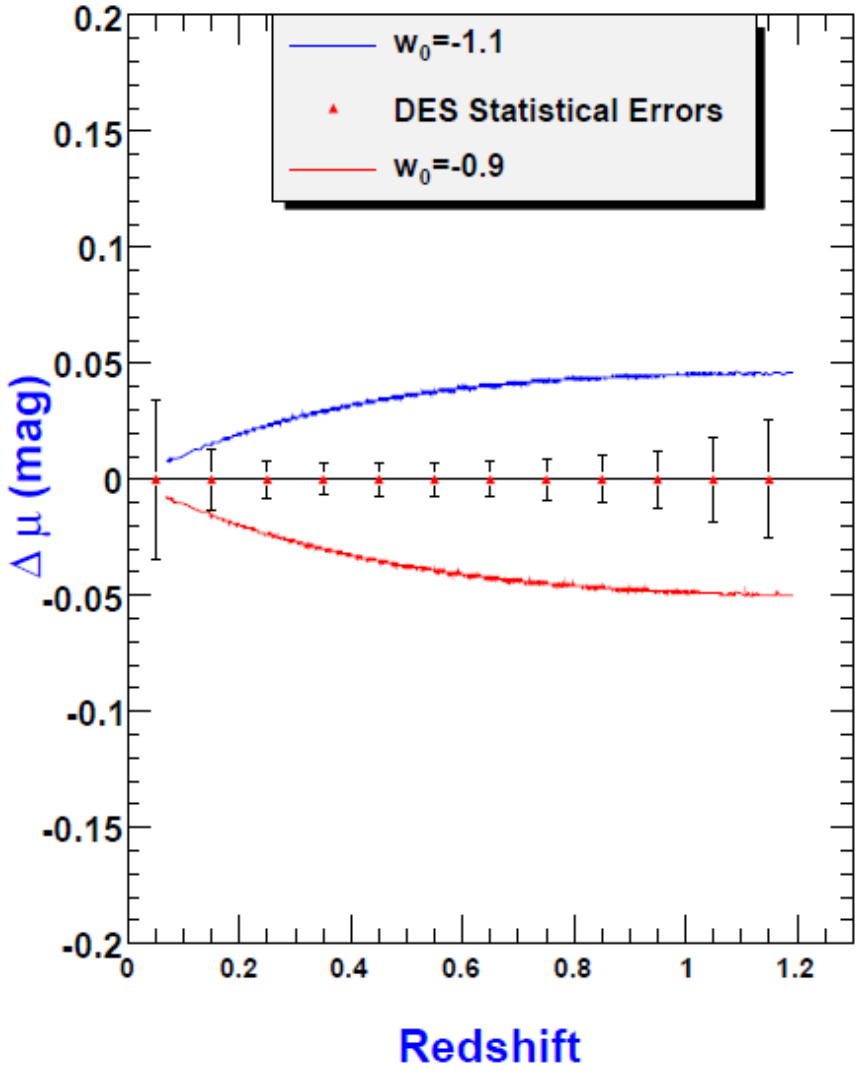


Comparison to recent measurements

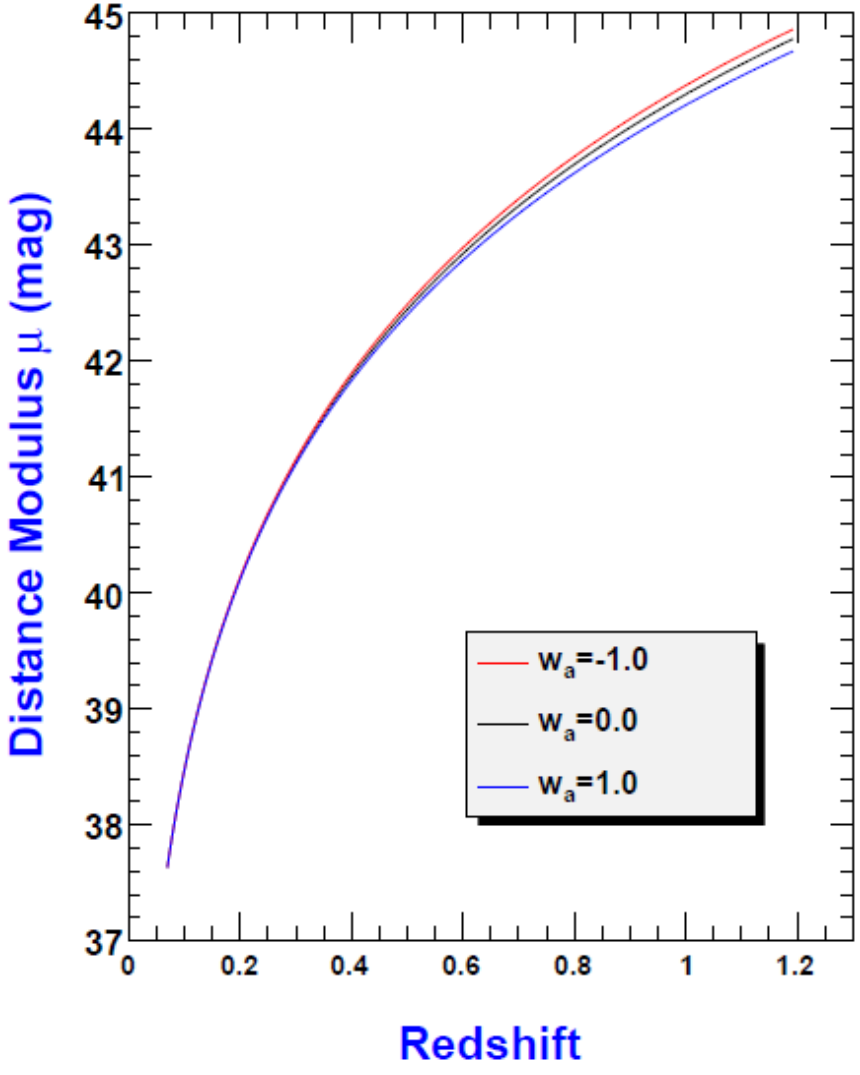


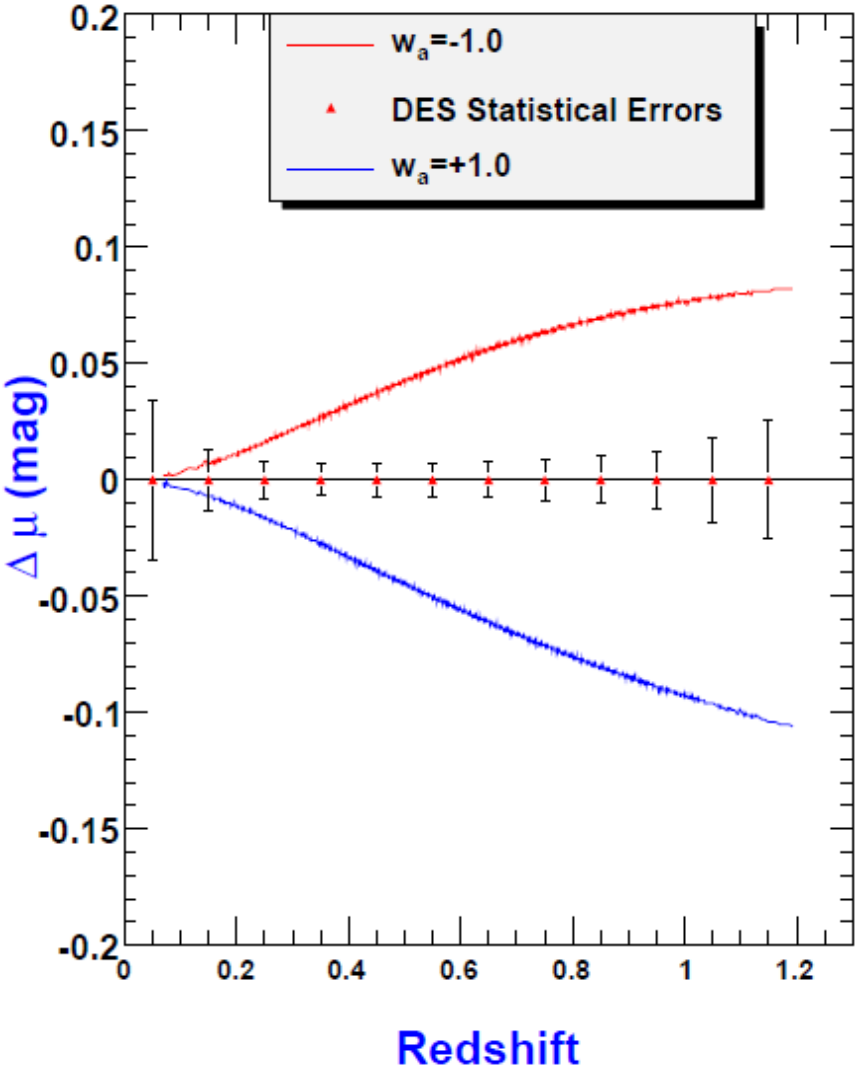
Cosmology Variations





Cosmology Variations



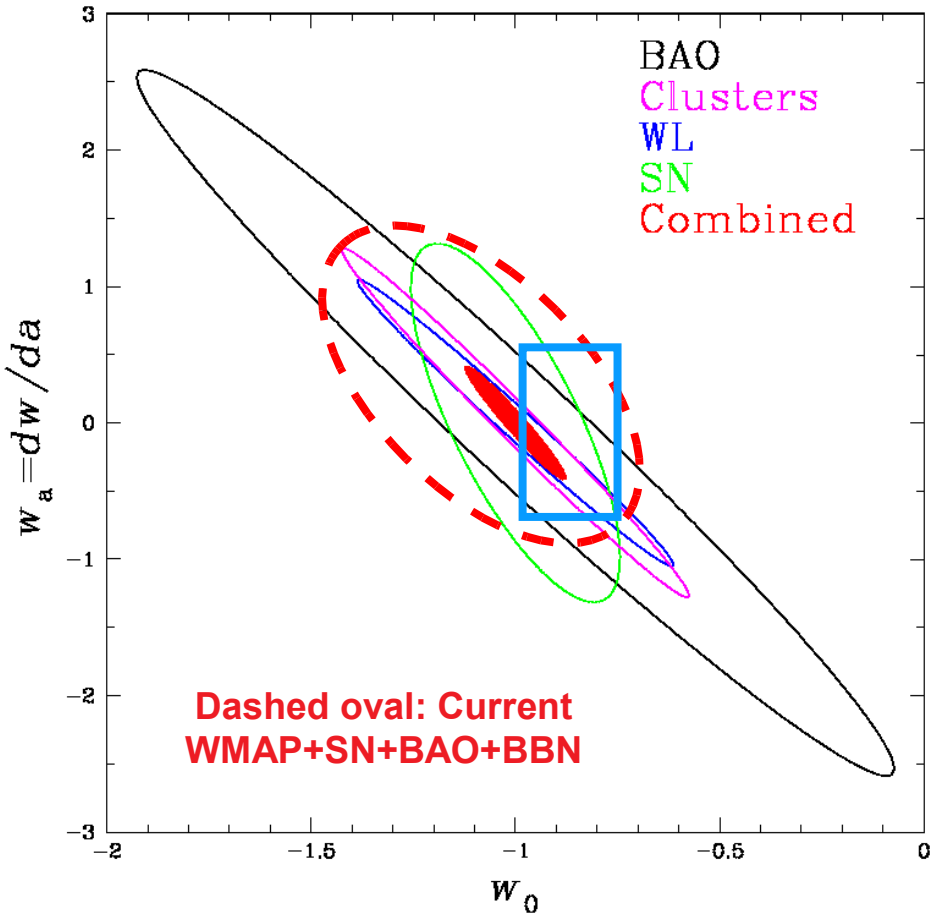


DES Key Science Projects

Four Techniques

- Galaxy Clusters
- Weak Lensing
- Baryon Acoustic Oscillations
- Supernovae

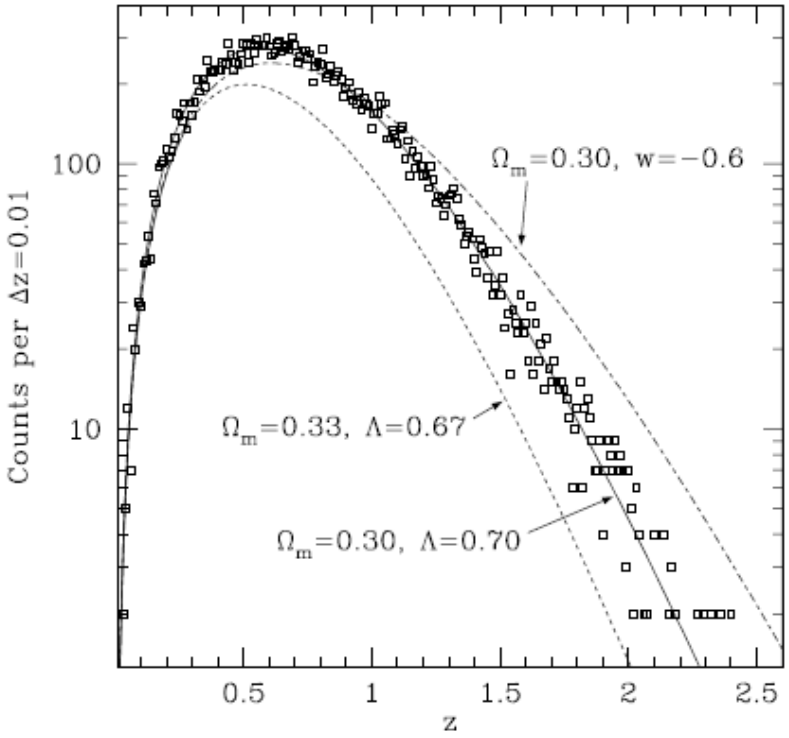
Rectangle shows region offset from center which could indicate new scalar fields such as from String Theory.
(Caldwell and Linder PRL2005)

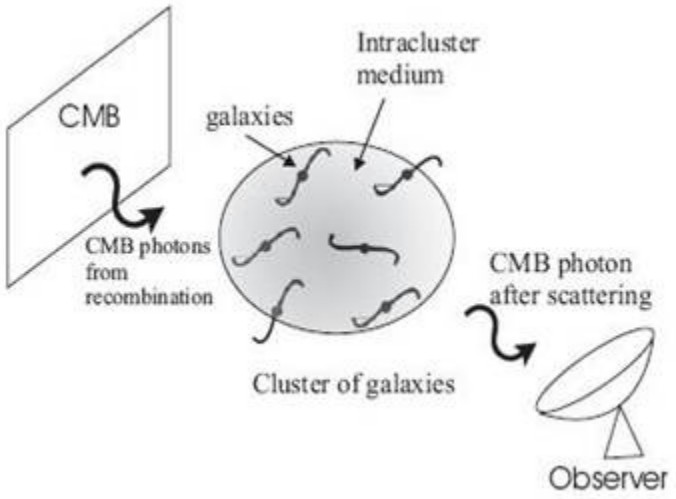


DES Provides x4.6 Improvement and uses all Four Techniques

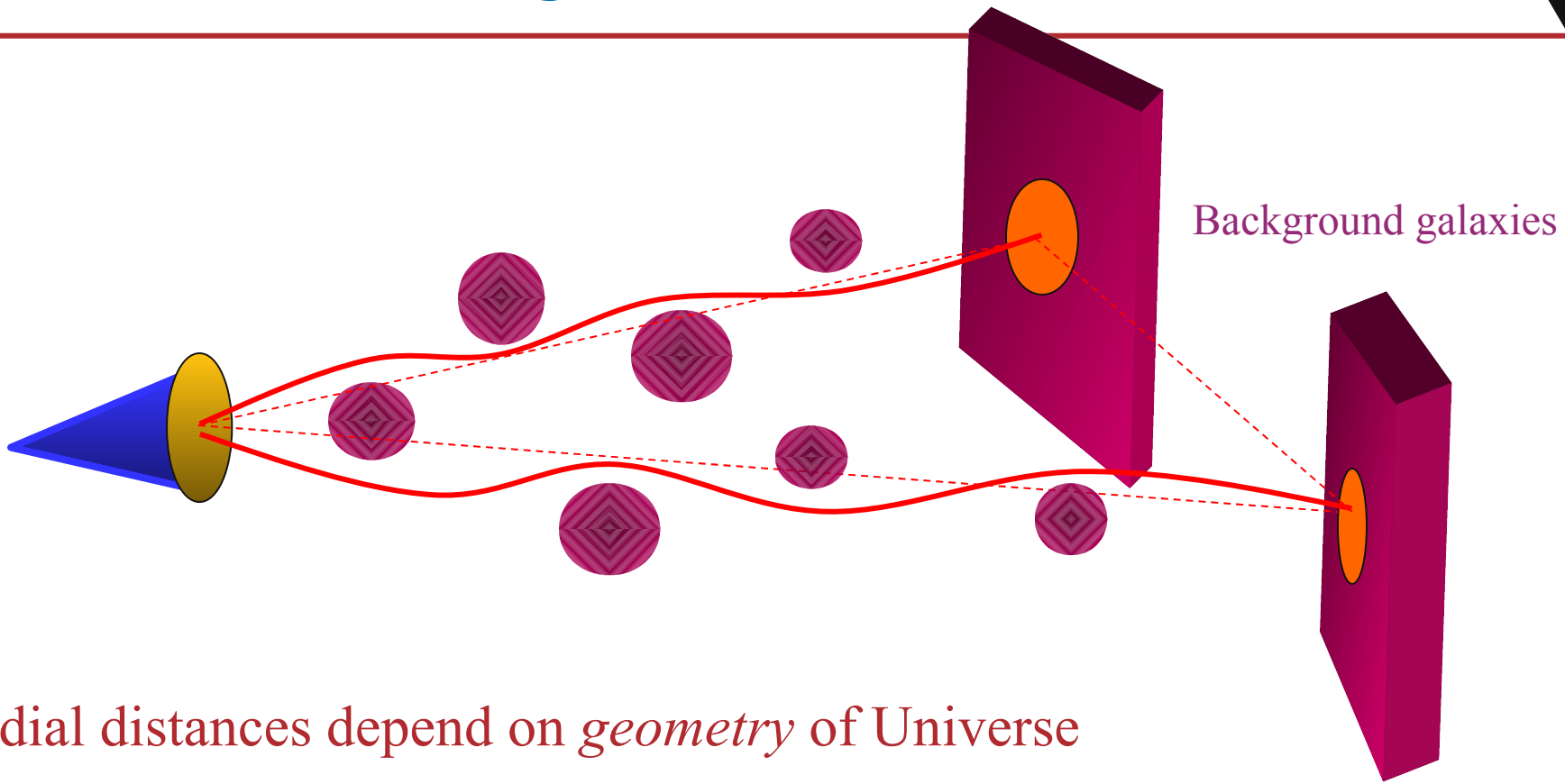
DES Galaxy Cluster Counts and the South Pole Telescope

- 170K optically- identified clusters
- 20K clusters to z=2 with confirmation/masses from the SZ effect measurement of the South Pole Telescope



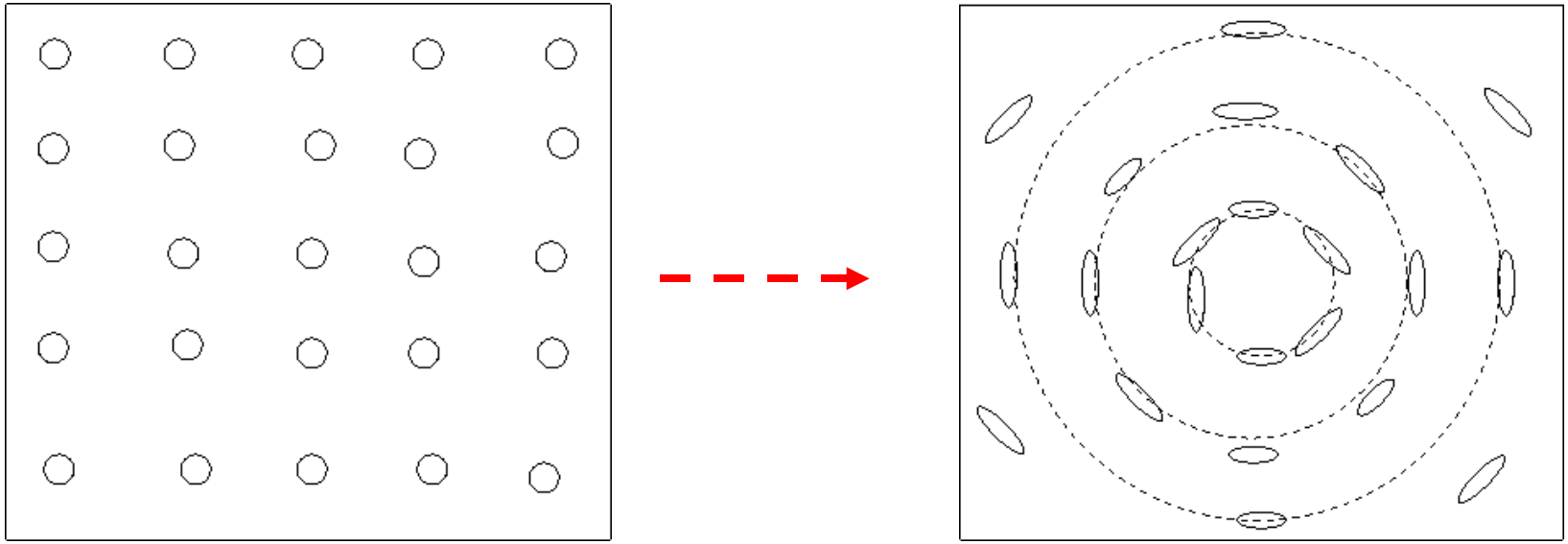


Weak Lensing of 300 Million Galaxies



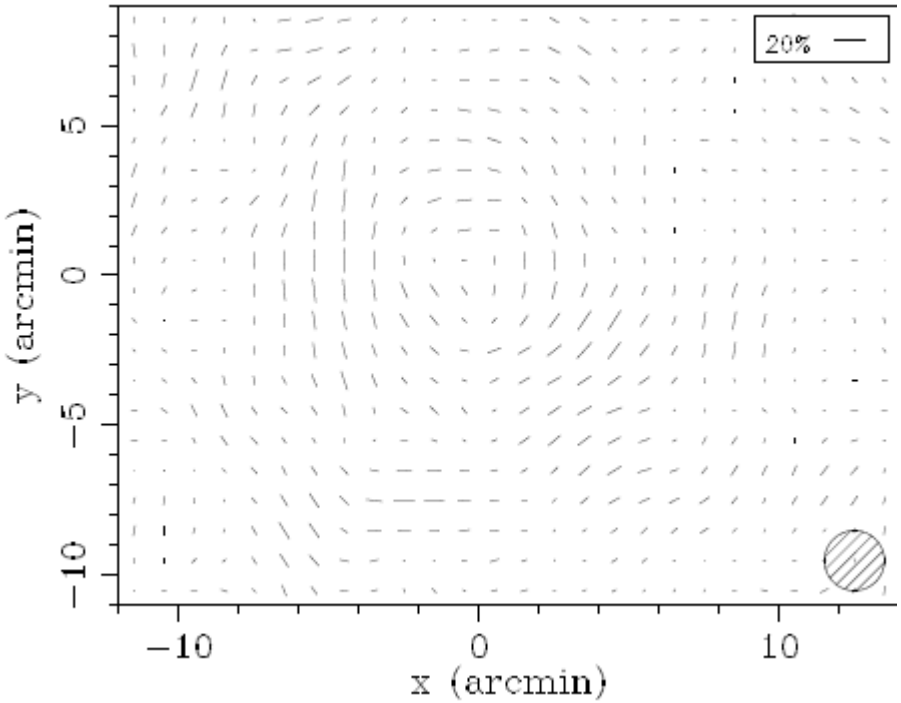
- Radial distances depend on *geometry* of Universe
- Foreground mass distribution depends on *growth* of structure

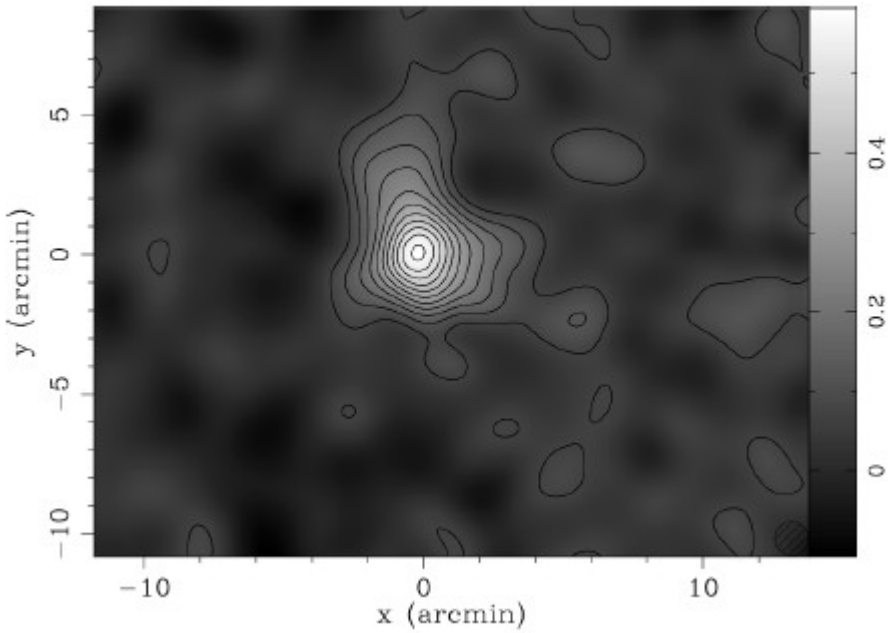
Lensing cartoon with mass in middle (not accurate!)



Weak Lensing Example Measurement

5700 background galaxies, 1 galaxy cluster in foreground causing shears, reconstructed mass distribution on right



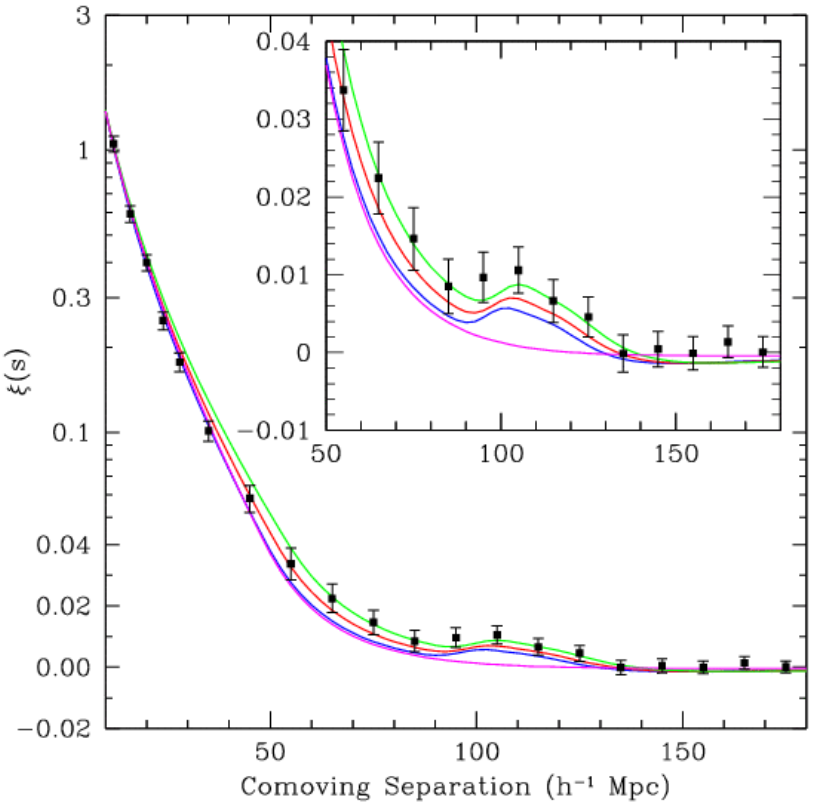


Umetsu et al. Mod Phys Lett A22, 2007

Baryon Acoustic Oscillations (see April 2008 Physics Today)

Plot shown is measurement of galaxy-galaxy correlation by SDSS, bottom curve is with no BAO, different colors are different levels of dark matter.

Much more sensitive to dark matter than dark energy, but less dark energy shifts the peak to the left.



Summary

- Dark Matter and Energy among the most compelling questions in science.

- Dark Energy Survey is a relatively small experiment that can have a big impact, and lay the groundwork for ~$500M next-generation experiments such as JDEM and LSST.

- ANL playing key roles in Supernova science, Mechanical Engineering, and detailed CCD studies.

THE END

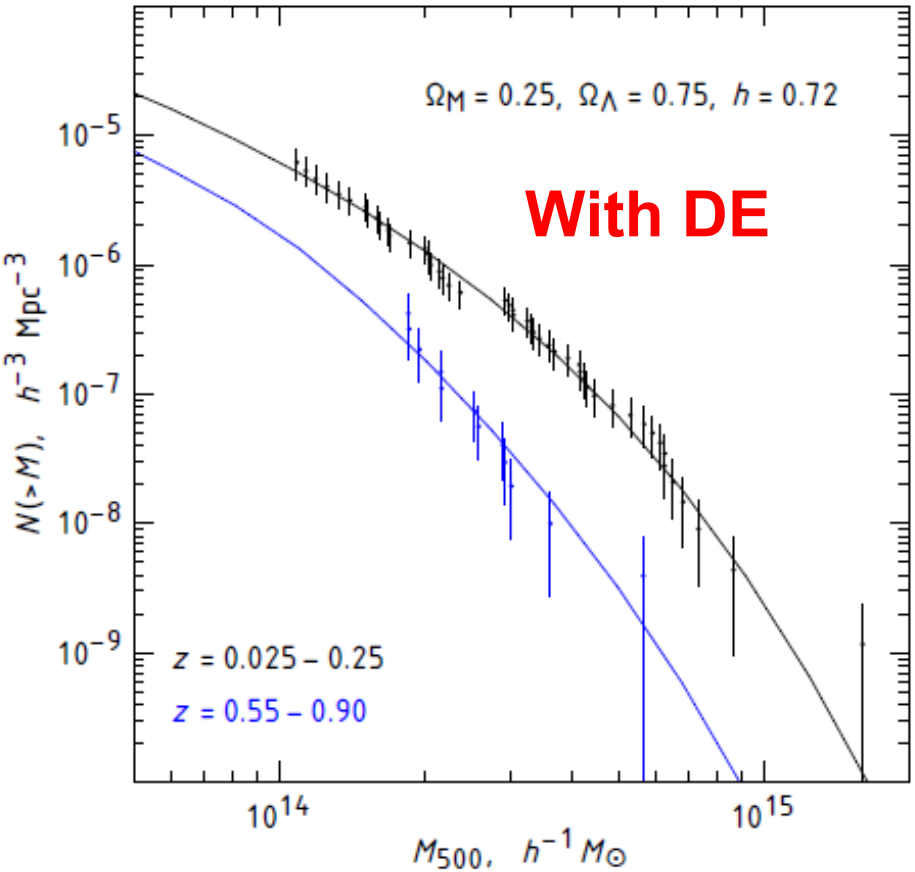
Backup slides…

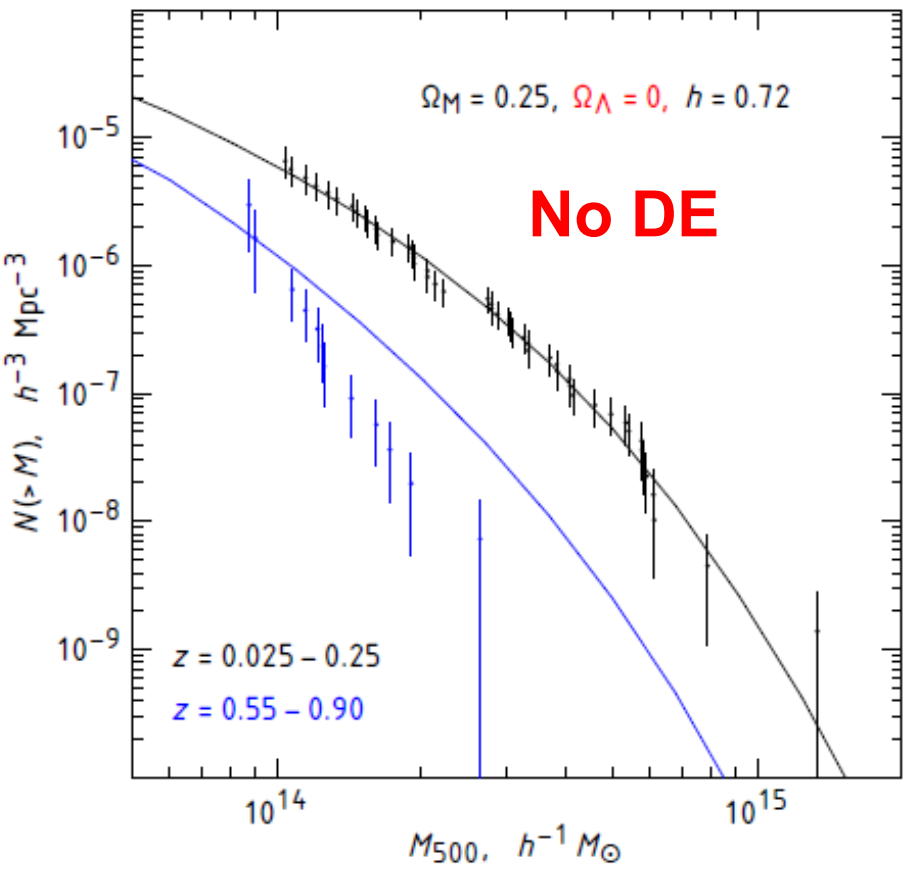
Galaxy Clusters Measured with X-Rays (>5 standard deviations with no DE)

CHANDRA CLUSTER COSMOLOGY PROJECT III: COSMOLOGICAL PARAMETER CONSTRAINTS

A. Vikhlinin[1,2], A. V. Kravtsov[3], R. A. Burenin[2], H. Ebeling[4], W. R. Forman[1], A. Hornstrup[5], C. Jones[1], S. S. Murray[1], D. Nagai[6], H. Quintana[7], A. Voevodkin[2,8]

Submitted 5/12/08; Revised 10/3/08; Accepted 10/29/2008



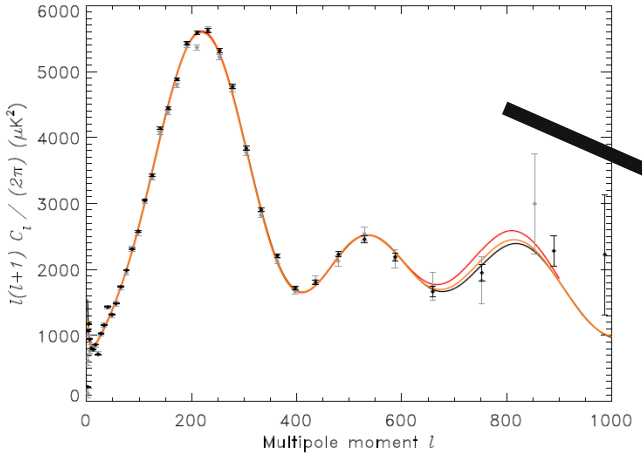


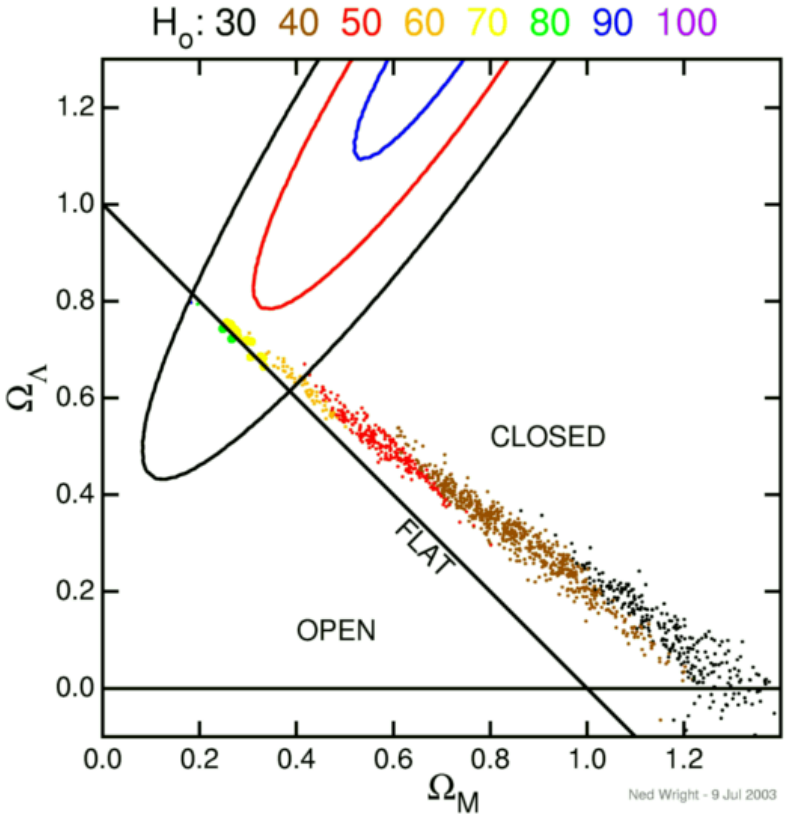
WMAP 5-year

TABLE 2
SUMMARY OF THE 95% CONFIDENCE LIMITS ON DEVIATIONS FROM THE SIMPLE (FLAT, GAUSSIAN, ADIABATIC, POWER-LAW) ΛCDM MODEL

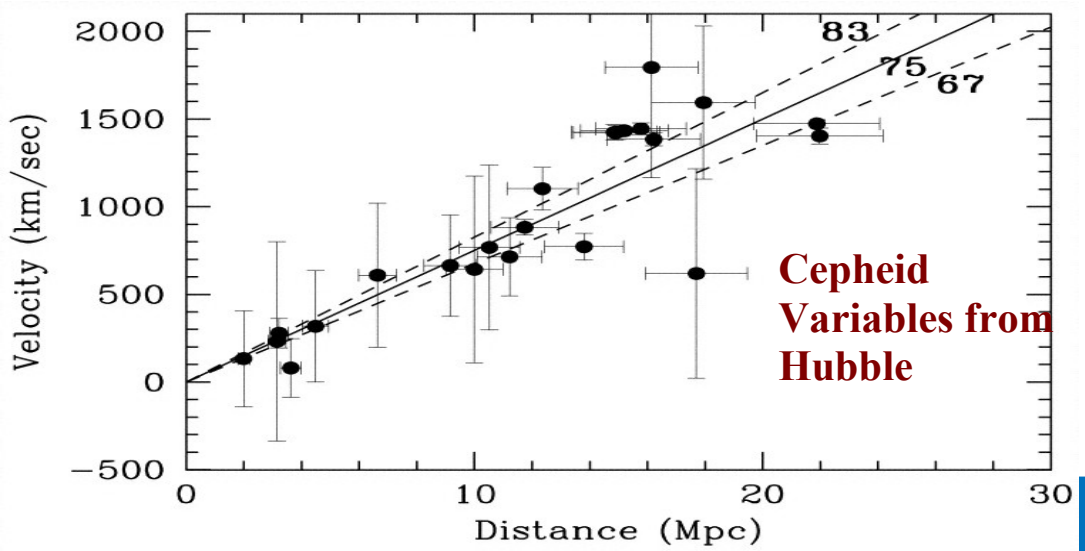
Section	Name	Type	*WMAP* 5-year	*WMAP*+BAO+SN
§ 3.2	Gravitational Wave[a]	No Running Ind.	$r < 0.43^{b}$	$r < 0.20$
§ 3.1.3	Running Index	No Grav. Wave	$-0.090 < dn_s/d\ln k < 0.019^{c}$	$-0.0728 < dn_s/d\ln k < 0.0087$
§ 3.4	Curvature[d]		$-0.063 < \Omega_k < 0.017^{e}$	$-0.0175 < \Omega_k < 0.0085^{f}$
	Curvature Radius[g]	Positive Curv.	$R_{\rm curv} > 12\ h^{-1}{\rm Gpc}$	$R_{\rm curv} > 23\ h^{-1}{\rm Gpc}$
		Negative Curv.	$R_{\rm curv} > 23\ h^{-1}{\rm Gpc}$	$R_{\rm curv} > 33\ h^{-1}{\rm Gpc}$
§ 3.5	Gaussianity	Local	$-9 < f_{NL}^{\rm local} < 111^{h}$	N/A
		Equilateral	$-151 < f_{NL}^{\rm equil} < 253^{i}$	N/A
§ 3.6	Adiabaticity	Axion	$\alpha_0 < 0.16^{j}$	$\alpha_0 < 0.067^{k}$
		Curvaton	$\alpha_{-1} < 0.011^{l}$	$\alpha_{-1} < 0.0037^{m}$
§ 4	Parity Violation	Chern-Simons[n]	$-5.9° < \Delta\alpha < 2.4°$	N/A
§ 5	Dark Energy	Constant w^{o}	$-1.37 < 1 + w < 0.32^{p}$	$-0.11 < 1 + w < 0.14$
		Evolving $w(z)^{q}$	N/A	$-0.38 < 1 + w_0 < 0.14^{r}$
§ 6.1	Neutrino Mass[s]		$\sum m_\nu < 1.3\ {\rm eV}^{t}$	$\sum m_\nu < 0.61\ {\rm eV}^{u}$
§ 6.2	Neutrino Species		$N_{\rm eff} > 2.3^{v}$	$N_{\rm eff} = 4.4 \pm 1.5^{w}$ (68%)

WMAP + H_0 gives snapshot of Ω_Λ but not w

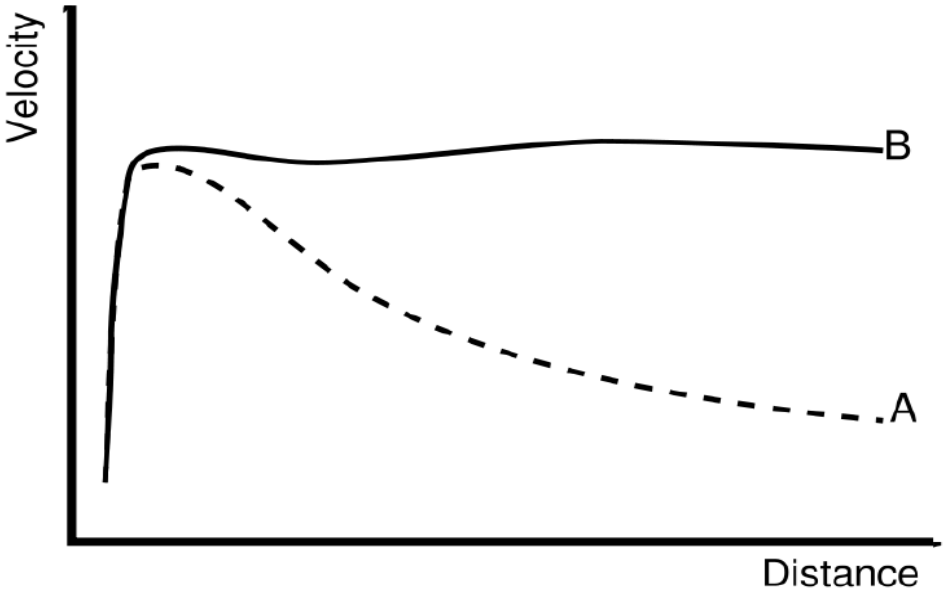




Example Hubble Constant Measurement



Dark Matter Evidence



Rotation curve of a typical spiral galaxy: (A) predicted by Newtonian dynamics, (B) observed. Dark matter can explain the velocity curve having a 'flat' appearance out to a large radius. Credit: Phil Hibbs. Or maybe need to modify Newtonian Dynamics? Stay tuned!

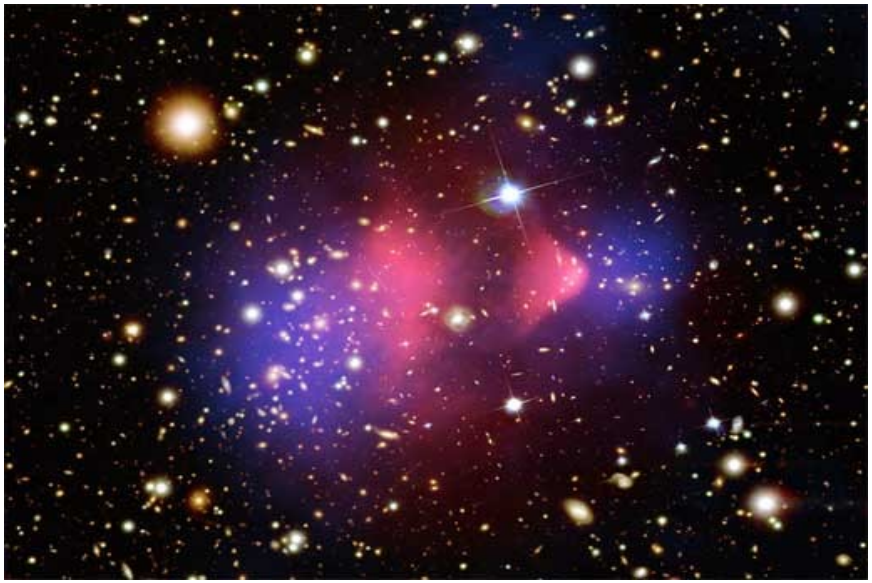
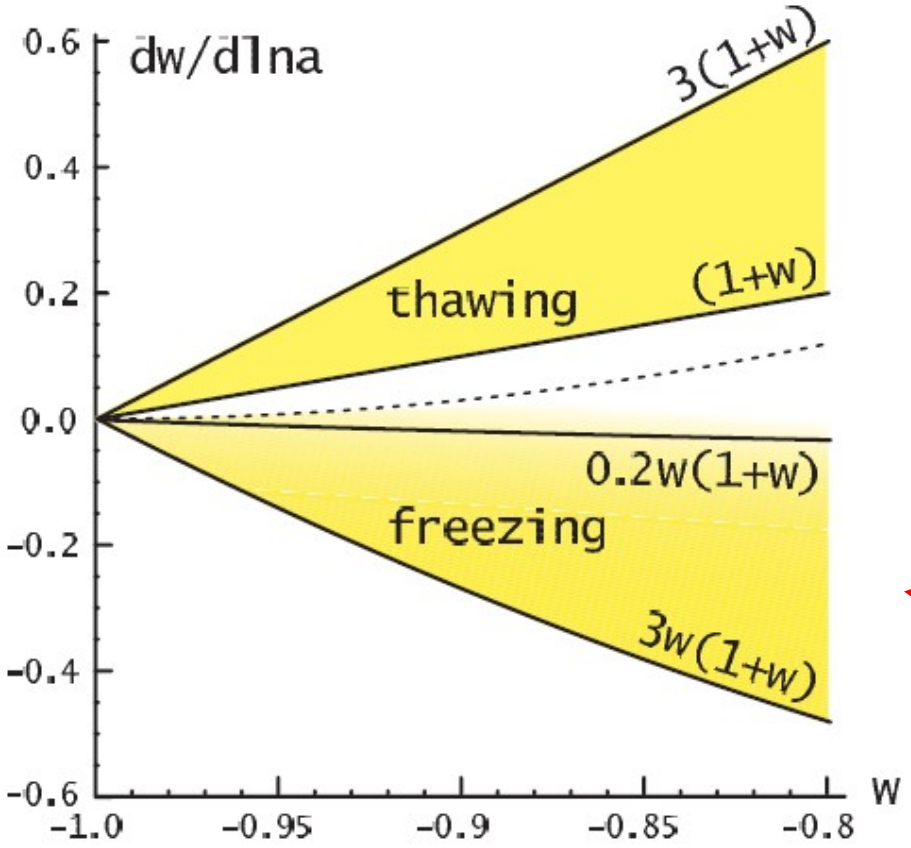


Image credit: X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.

Scalar Field Models: "Quintessence"

Caldwell and Linder PRL 2005



Models include the "dilaton" from string theory and the "dark energy axion"

"Tracking" models that are relatively insensitive to initial conditions

Zlatev, Wang, Steinhardt PRL 1999